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STRATIGRAPHIC SETTING, FACIES ANALYSES AND DEPOSITIONAL ENVIRONMENTS OF THE EOCENE IRONSTONES OF GABAL GHORABI MINE AREA, EL BAHARIYA DEPRESSION, WESTERN DESERT, EGYPT

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ABSTRACT

The Eocene ironstone section of Gabal Ghorabi mine area represents an unconformity-bounded condensed succession, exhibiting a lateral facies change towards the equivalent relatively thicker carbonates of the surrounding scarps. It rests unconformably on different horizons of the underlying folded Cenomanian Bahariya Formation and is subdivided into two main shallowing-upward ironstone sequences, separated by an intra-Eocene (paleokarst) unconformity.

The lower ironstone sequence comprises four ironstone facies namely: a) lagoonal/tidal flat mud-ironstone facies that represents deposition from suspension in low energy water condition, b) lagoonal fossiliferous ironstone facies (proximal tempestite), well developed in the southern sector of Gabal Ghorabi mine area, c) shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstone facies, dominated in the southern and central sectors of Gabal Ghorabi, and d) Shallow subtidal nummulitic ironstone facies, that dominated in the northern sector. The shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstone facies and the shallow subtidal nummulitic ironstone facies comprise peritidal facies association and developed on submarine swell during a general shoaling-upward tendency and sea level fall.

The upper ironstone sequence begins by the deposition of shallow subtidal green mudstone facies as a result of a new marine transgression followed by a peritidal ironstone sequence, which consists of three repeated shallowing-upward cycles. Each cycle begins by shallow subtidal mud-ironstones grading upward into shallow subtidal-intertidal nummulitic-bioclastic ironstones and terminated by supratidal stratiform barite (DCRs). The upper ironstone sequence is intensively lateritized and karstified and iron ore laterite and stratabound karst-related barite are formed.

Keywords: Stratigraphy, facies analyses, depositional environments, G.Ghorabi, El-Bahariya, Egypt

INTRODUCTION

Ghorabi-Nasser area is located at the extreme northeastern corner of the Bahariya Depression at about 25km west of El Bahariya-Cairo road (Fig. 1). It is bounded by the following coordinates: 29° 00' to 29° 4' E, and 28° 29' 30" to 28° 30' 30" N. The area is a topographically high feature, attaining about 2.3 sq. km and it is completely separated from the surrounding Eocene carbonate scarp by deep structural and erosional wadis. To the north, the structurally controlled fault wadi separates Gabal Ghorabi from the scattered hills of Nasser area and the karstified Eocene carbonates. At the south, Gabal Ghorabi directly overlooks the Bahariya Depression and the surrounding wadis are opened into the main Depression. The core of Gabal Ghorabi is made up of the Cenomanian clastics of the Bahariya Formation, which is unconformably overlain by Eocene ironstone succession and the related duricrusts. In some places, discontinuous Oligocene pebbly sandstone beds unconformably overlie the Eocene ironstone succession.

The regional geology of El Bahariya Depression and the surrounding plateau in general and the iron ore genesis in particular were reviewed by El Aref and Lotfy (1989); Khalil (1995), and Salama (2005). The recent work of Khalil (1995) and El Aref *et al.* (1999) classified the Cretaceous and Eocene ironstones into six genetic types, being arranged from base to top as follows: 1) Cenomanian ironstone bands and lenses; 2) Stratabound lateritic ironstones confined to the Cretaceous-Eocene unconformity; 3) Stratiform shallow marine ooidal-pisolitic ironstones; 4) Lagoonal bedded ferruginous mudstones and dolostones; 5) Stratabound karst iron ore and conglomerates; 6) Bartonian glauconitic iron laterites of El Hamra Formation.

Helba *et al.* (2001) and El Aref *et al.* (2001) studied the "Lutetian" ironstone succession (Naqb and Qazzun formations) of El Harra and El Gedida mine areas and subdivided it into four ironstone units; being arranged from base to top as follows: Lower variegated mud-ironstone, Lower ooidal, oncolitic and nummulitic ironstone, Upper variegated mud-ironstone and an Upper nummulitic ironstone. They also studied the "Lutetian" carbonate succession and differentiated it into five stratigraphic units, which can be easily traced all over the northeastern Plateau of El Bahariya Depression. These are lower dolomitic

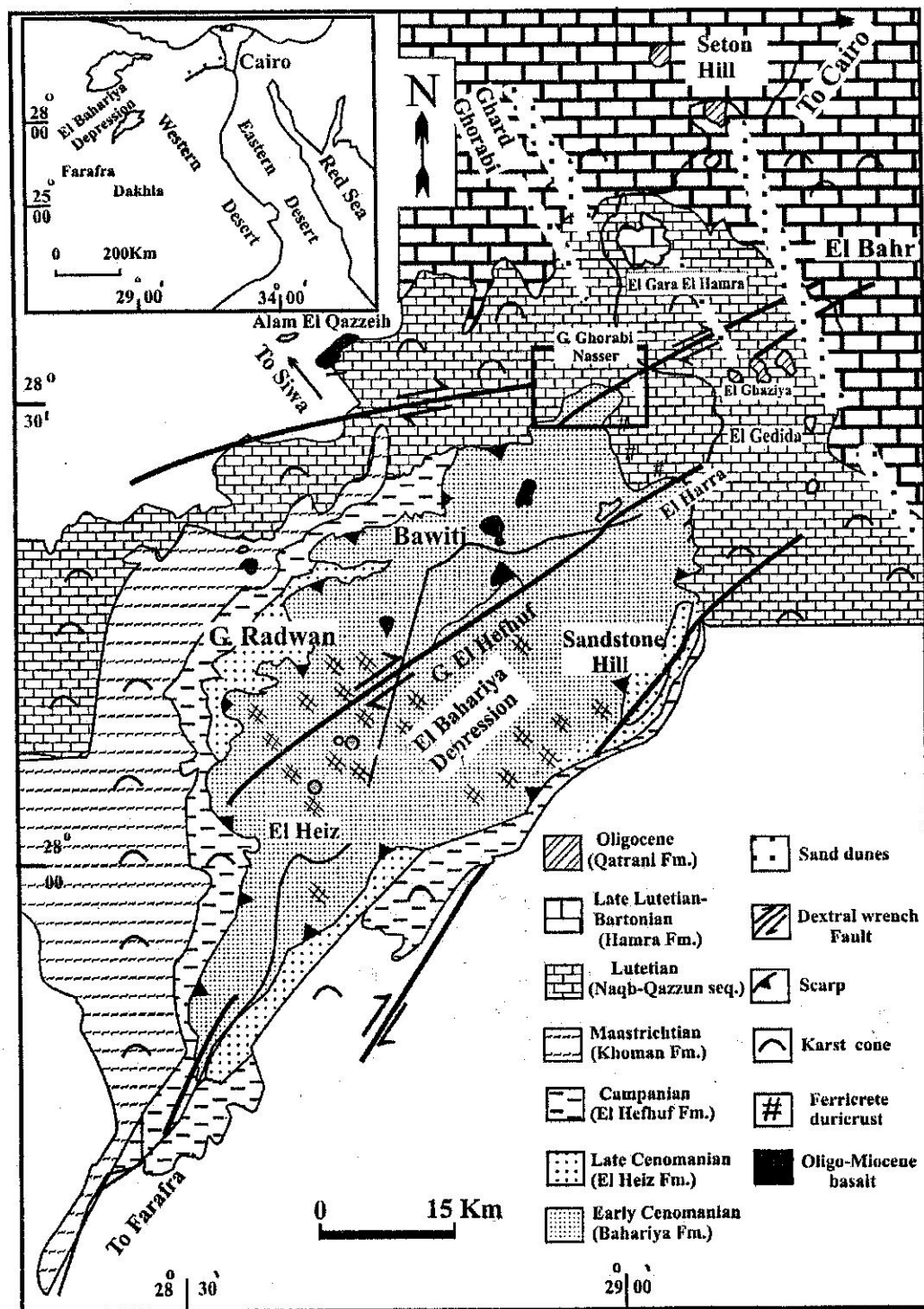


Fig.1. Geological map of El Bahariya Depression (modified after Hermina et al., 1989, detailed structural elements are shown in Sehim, 1993).

limestone and dolostone, Lower nummulitic limestone, Upper dolomitic limestone and marl, Middle nummulitic limestone and Upper nummulitic chalky limestone. They concluded that the ironstone succession represents a reduced section relative to the surrounding equivalent thick carbonate succession and they are deposited on a ramp depositional environment.

OBJECTIVES

The present study deals with the stratigraphic setting, facies analysis and depositional environments of the Eocene ironstone succession of Gabal Ghorabi mine area. To achieve these goals, four representative lithostratigraphic sections covering the ironstones of Gabal Ghorabi mine area and two carbonate sections are measured, described and correlated with each others. The stratigraphic measurements and mega- and microscopic features tend to define the main ironstone units, internal lithologic subdivisions, discontinuity surfaces as well as their lateral and vertical lithologic changes. The bulk chemical composition of the different ironstone types is determined by XRF. The terminology of the ironstone microfacies is adopted from the classification of Young (1989) that depends on the different ratio of intrabasinal and extrabasinal components.

REGIONAL STRATIGRAPHY AND STRUCTURES

The stratigraphic succession of the northeastern plateau of El Bahariya depression includes the following rock units, being arranged from younger to older (El Aref *et al.*, 1999):

8- Wadi and playa deposits and eolian sand dunes	Quaternary	
7- Duricrusts (calcrete, silcrete and ferricrete)	Miocene?-Quaternary	
-----Unconformity-----		
6- Volcanic rocks (basalt)	Oligo-Miocene	
5- Qatrani Formation	Oligocene	
-----Regional unconformity (paleokarst)-----		
4- El Hamra Formation	Eocene	
-----paleokarst-----		
3- Qazzun Formation		
2- Naqb Formation		
-----Regional unconformity-----		
1- Bahariya Formation	Cenomanian	
-----Base unexposed-----		

The Bahariya, Naqb and Qazzun formations are represented in Gabal Ghorbi mine area. The Early Cenomanian Bahariya Formation (Said, 1962) forms the floor of the Bahariya Depression and the foot of the surrounding scarps. The most obvious feature of the Bahariya Formation is the occurrence of the ironstone bands, particularly in the lower and upper intervals of the exposed sections. In Gabal Ghorabi area, the studied ironstone succession truncates the upper mudstone-sandstone member in the southern and northern sectors (Plate 1A) and truncates the sandstones of the middle Member in the central sector.

The Eocene Naqb and Qazzun formations (Lutetian, Said and Issawi, 1964; Ypresian, Strougo *et al.*, 1990 & Strougo, 1996) are dominated by karstified nummulite-rich limestones, which differ from the underlying clastic-dominated Bahariya Formation and the overlying mixed carbonate-clastic lithologies of El Hamra Formation. The Naqb Formation is composed mainly of yellowish white dolomitic and nummulitic limestones with distinct pinkish and reddish tones. The Qazzun Formation is characterized by its snow-white chalky and nummulitic limestones with remarkable zones of large melon-shaped silicified limestone concretions (average diameter 50-60 cm). The carbonates of the Naqb and Qazzun formations are dominantly cavernous and display diagnostic megascopic and microscopic karst features and intimately associated with soil processes, comprising dissolution, cementation, dolomitization, dedolomitization and deposition of autochthonous soil residual materials and allochthonous cave deposits. Such alteration processes obscured, to a large extent, the original lithofacies, bedding geometry, internal sedimentary structures and obliterated their fossil content (El Aref *et al.* 1987 and Lotfy, 1988).

The Bahariya area is dissected by several fault belts, among which there are two master fault systems: 1) El Gedida-El Harra dextral fault (El Bahariya mid fault). This fault system extends from El Gedida to El Harra mine areas and crossing through the floor of the Bahariya Depression, 2) Ghorabi-El Ghaziya fault system, which extends from Gabal Ghorabi to El Ghaziya area in a NE-direction for about 36 km with an average width of about 9 km (Fig. 1). Gabal Ghorabi represents the central segment of the giant Ghorabi-El Ghaziya structural belt (Fig. 2).

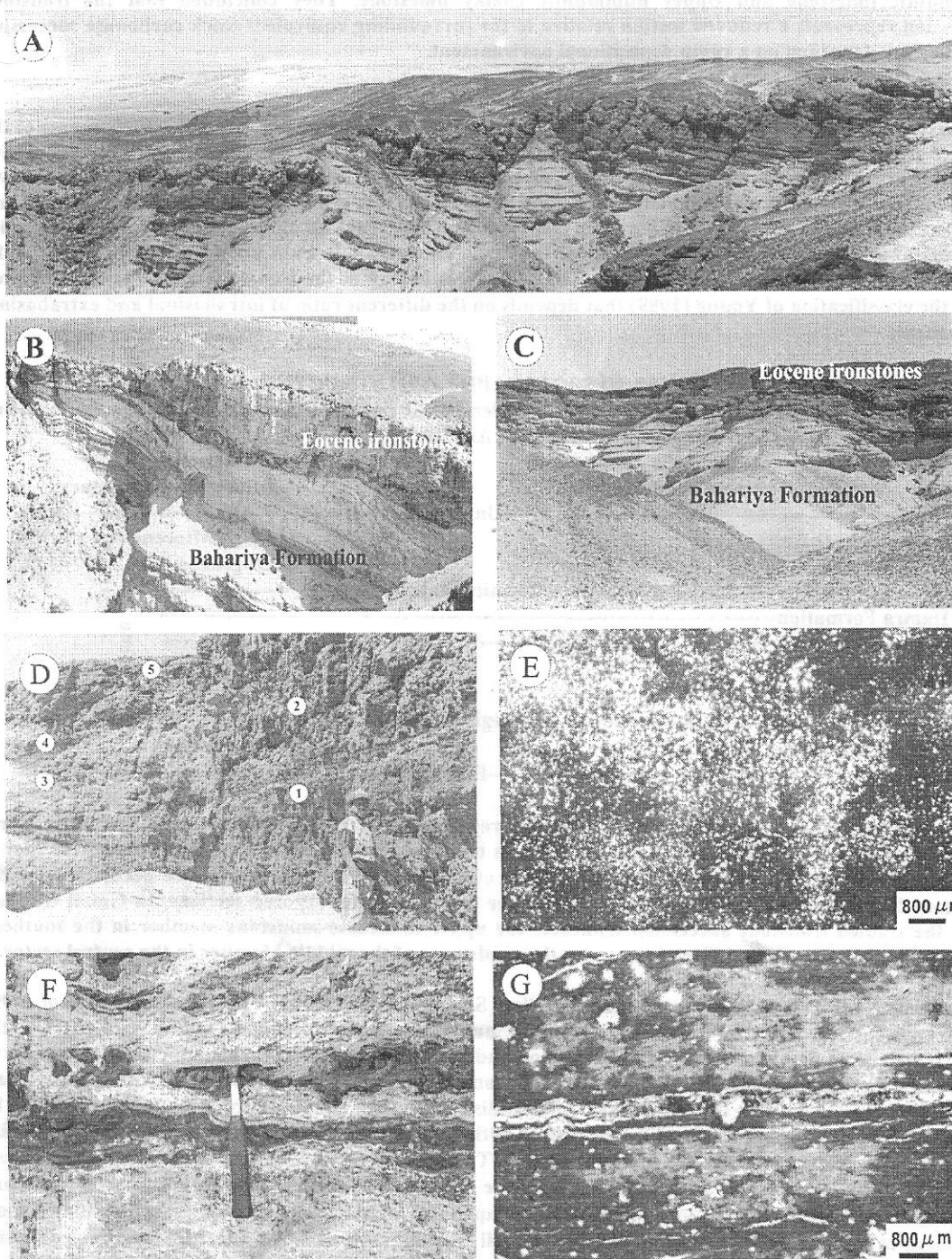


Plate 1. A) The Eocene ironstone succession overlies the Cenomanian clastics of the Bahariya Formation. Note the effect of minor step faults on both the Bahariya Formation and ironstone succession; B) Angular unconformity between the tilted and dragged Cenomanian clastics of the Bahariya Formation and the overlying Eocene ironstones along the master fault of Gabal Ghorabi; C) The Eocene ironstone succession overlies the Cenomanian clastics of the Bahariya Formation. Note the effect of minor step faults on both the Bahariya Formation and the ironstone succession; D) General field view of the ironstone succession of the southern sector of Ghorabi mine area; 1= mud-ironstone unit; 2= fossiliferous ironstone unit; 3= nummulitic-oolitic-oncolitic ironstone unit; 4= barite-bearing mudstone unit, and 5= lateritized iron ore unit; E) The mottled appearance and color variations in the burrow-mottled mud-ironstone, PPL; F) Field photograph of the laminated kaolinitic mudstone and glauconitic ironstone of the lower mud-ironstone of the eastern part of the southern sector. Notice the presence of reddish brown stratiform ironstone concretions; G) Thinly laminated yellowish brown glauconitic mud-ironstone contains sub-angular quartz grains and silica spherules, PPL. PPL. = Plane Polarized Light

The eastern segment of this structural belt affects the Eocene rocks on the eastern plateau of the depression and is represented by several small right-stepped, en-echelon folds. The western segment of Gabal Ghorabi-El Ghaziya structural belt consists of W- to WNW-oriented, left-stepped en-echelon faults. The master fault displaces the southern sector of Gabal Ghorabi downward (hanging wall). Gabal Ghorabi fault (master fault) dips at 62° due south (Moustafa *et al.* 2003) with a vertical displacement of about 40 m (El Akkad and Issawi, 1963). A set of minor step normal faults trending E-W cuts across the Eocene ironstone succession of the southern and northern sectors. The crest of this anticline was continuously eroded, whereas its flanks were subsequently onlapped by the Eocene ironstone succession. The Eocene ironstone succession unconformably overlies the Cenomanian clastics of the Bahariya Formation with clear angular unconformity relationship at the fault plane due to drag (Plate 1B). Two phases of movement are recorded on the master fault; the earlier movement is indicated by the southward dipping of the Bahariya Formation on the southern side of the fault due to drag. The later movement led to the displacement of the Eocene ironstone succession of the Naqb Formation, which unconformably overlies the dipping Bahariya beds.

STRATIGRAPHIC ARCHITECTURE OF GHORABI IRONSTONES

Four detailed lithostratigraphic sections representing the ironstone successions of the study area are carefully measured, described and correlated with two carbonate sections in the surrounding eastern and northern carbonate scarp (Fig. 2). The ironstone succession of Gabal Ghorabi represents a relatively reduced and condensed section (up to 23 m thick) relative to the surrounding thick carbonate succession of the northeastern plateau of El Bahariya Depression (68 m thick, Said and Issawi, 1964). According to the lithological characteristics of the ironstone successions, Gabal Ghorabi area is subdivided into three main sectors separated by two major NE-SW right lateral strike-slip and normal faults (Fig 2). These are: southern, central, and northern sectors. The Ghorabi ironstone succession can be subdivided into two characteristic sequences; the lower and the upper ironstone sequences, which are correlated with the lower and upper iron ore units of Said and Issawi (1964). The geographic distribution of the lower ironstone sequence all over Gabal Ghorabi mine area indicates that it displays great lateral and vertical variations in thickness and lithological aspects. These variations are related to the paleotopography and the configuration of the underlying Cenomanian Bahariya Formation as well as the syntectonic elements prevailed during the Post-Cenomanian-Pre- Eocene time span. The different rock-stratigraphic units of these ironstone sequences and their lateral variations as well as the associated paleosols and surficial duricrusts are shown in Table 1.

The lower ironstone sequence is rich in fossil molds and casts as well as ferriferous ooids, peloids and oncoids. It is separated from the underlying Cenomanian Bahariya Formation by a thin layer of oligomictic, intraformational conglomerates and separated from the overlying lateritized (karst) iron ore unit by a characteristic brick red hematitic mud-ironstone (paleosol horizon).

The upper ironstone sequence forms the vertical cliff segment of the main scarp of Gabal Ghorabi and consists mainly of a basal of olive green to greyish white laminated mudstone unit grading upward into three repeated shallowing-upward cycles of mud- and nummulitic-bioclastic ironstones and thin bed of stratiform barite. Thin sandstone beds of the Oligocene Qatrani Formation with or without hard cap of silcrete or ferricrete duricrusts are often observed. The upper ironstone sequence has the same lithological characters and is highly lateritized giving rise to highly collapsed iron ore type with varieties of re-deposited crustified and colloform iron and manganese oxides and hydroxides together with surficial ferricrete duricrust.

FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENTS

A. The lower ironstone sequence

1. Mud- Ironstone Facies (2-4 m)

The mud-ironstone facies is composed mainly of varicolored bioturbated mud-ironstones and it is subdivided into two lithological horizons (Fig. 3, Plate 1D): The lower horizon (2-2.5 m thick) consists of dark violet to black manganese-rich hematitic burrow-mottled mud-ironstone facies (Plate 1E), containing few scattered ferruginized nummulite tests. Microscopically, the mud-ironstones consist of sub-rounded light brown to black hematitic peloids mixed with angular sand-sized quartz grains and biomouldic cavities of ferruginized nummulite tests and skeletal algae. These components float in bioturbated amorphous iron and manganese oxyhydroxides matrix. The upper horizon (1-1.5 m thick) consists of thinly laminated brick red hematitic-goethitic mud-ironstone facies. It shows gradational contact with the underlying burrow-mottled mud-ironstones. This facies exhibits features indicating short period of subaerial exposing such as desiccation cracks and alveolar texture. Eastwards in the southern

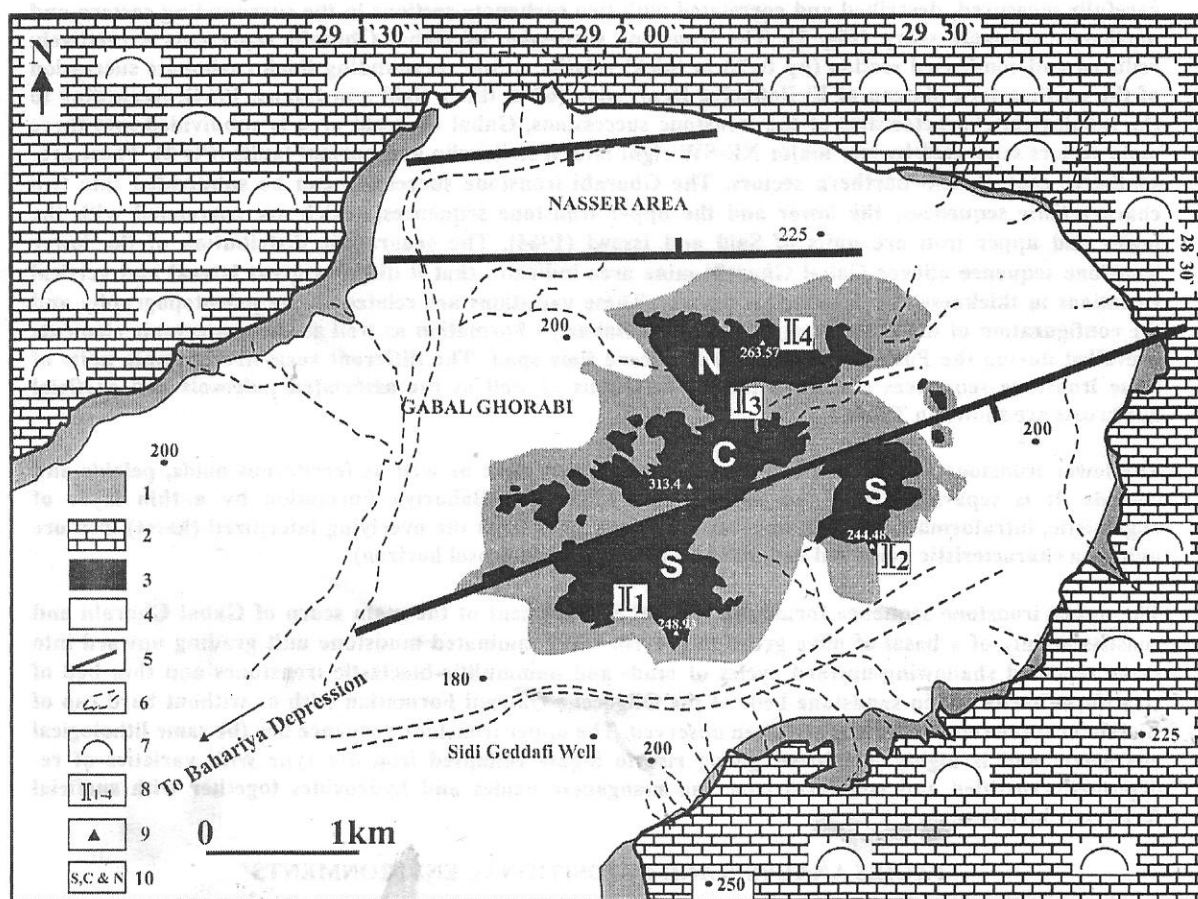


Fig.2. Simplified geological map of Ghorabi-Nasser area (based on the geological map of El Aref and Lotfy, 1989). 1) Clastic rocks of the Cenomanian Bahariya Formation; 2) Karstified limestones of the Eocene Naqb Formation; 3) Iron ore deposits; 4) Quaternary sediments; 5) Faults; 6) Drainage lines; 7) Cone karst; 8) Measured ironstone sections (I-4) and carbonate sections (S and C); 9) Triangulation points; 10) southern (S), central (C) and northern (N) sectors of Ghorabi mine area.

Table 1. Distribution of the different rock-stratigraphic units of the lower and upper ironstone sequences of Ghorabi mine area.

Age	Formation	Sequence	Sectors (Fig. 2)		
Oligocene	Qatrani	---	Southern sector (sections 1, Fig. 3 and section. 2, Fig. 4)	Central sector (section. 3, Fig. 5)	Northern sector (section. 4, Fig. 6)
			Siltcrete or Ferricrete Duricrusts		
	Ferruginous and silicified fluvial planar and trough cross-stratified gravely sandstones and conglomerate lenses with subordinate limonitic mudstone interbeds				
	Unconformity				
Eocene	Nagb	Upper ironstone sequence	Lateritized (karst) ironstone unit	Lateritized (karst) ironstone unit associated with stratiform and stratabound barite deposits	Lateritized (karst) ironstone unit
		Mudstone unit			
	Lower ironstone sequence	Paleosol and Ironstone Breccias			
		■ Nummulitic-oidal- oncolitic ironstone unit ■ Fossiliferous ironstone unit ■ Mud-ironstone unit	■ Nummulitic-oidal-oncolitic ironstone unit ■ Stromatolitic ironstone unit		■ Nummulitic ironstone unit ■ Mud-ironstone unit
		Cenomanian-Eocene unconformity			
Cenomanian	Bahariya	---	kaolinitic and glauconitic mudstones containing ironstone bands and lenses	Barite-bearing ferruginous sandstones	kaolinitic and glauconitic mudstones containing ironstone bands and lenses

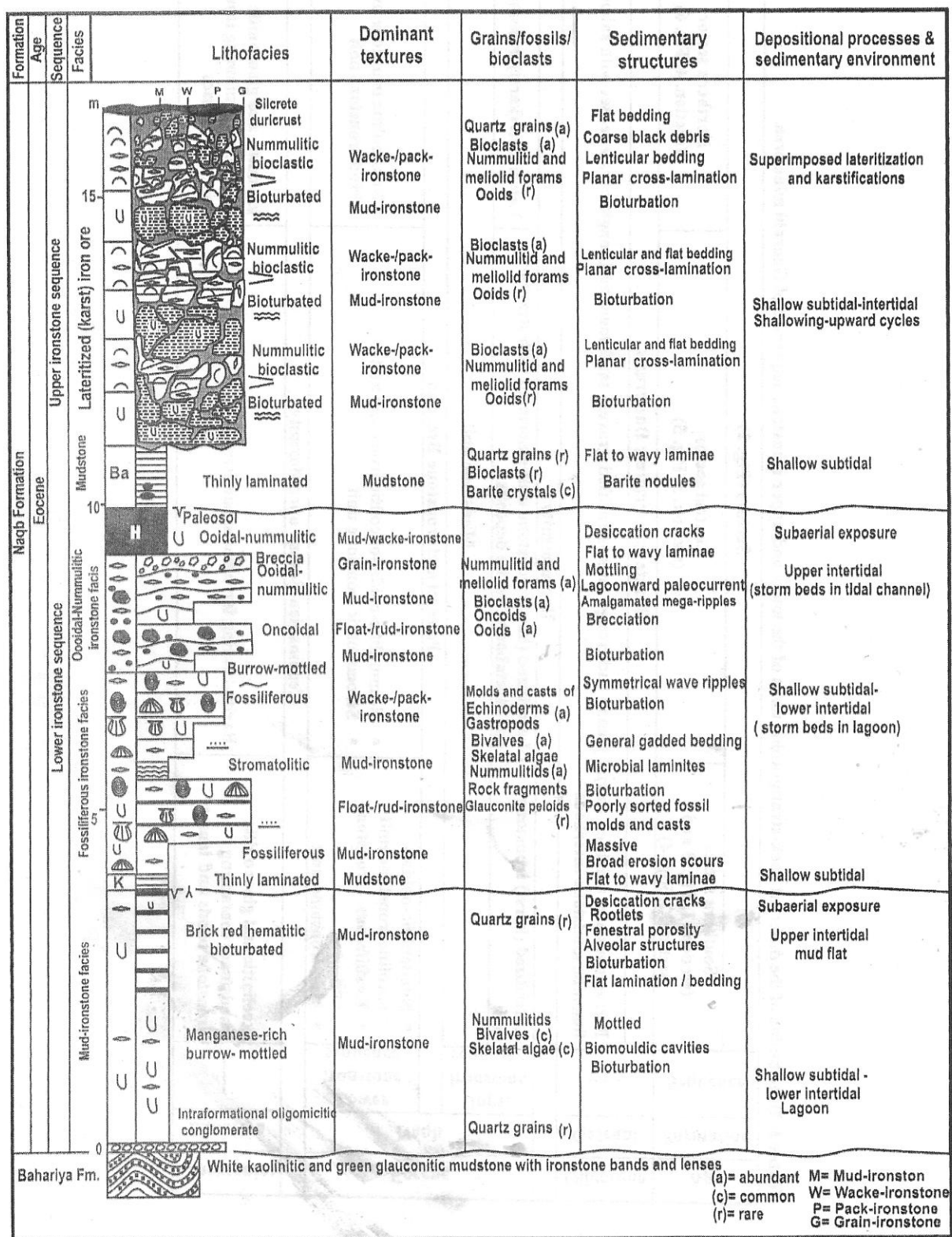


Fig.3. Facies analyses and depositional environment of the Eocene ironstones at the western part of the southern sector of Gabal Ghorabi mine area (section 1, Fig.2).

sector (Fig. 4), the lower mud-ironstone unit (1 to 1.5 m in thickness) changes laterally into glaucony-bearing small-scale shoaling-upward cycle. The lower part of this cycle is formed of thinly laminated kaolinitic and glauconitic mudstone, grading upward into thinly laminated egg-yellow mud-ironstone facies, containing sub-rounded to elongate irregular lenses and pockets of dark red to black hematitic ironstone (Plate 1F and 1G). Northward, the mud-ironstone unit is similar, to a large extent, to that described in the southern sector. The XRF analyses of this facies are shown in Table 2.

Depositional Environment

The low faunal diversity and abundance, intensive bioturbation and clotted fabric of the mud-ironstone facies suggest deposition from iron-rich colloidal suspension in shallow subtidal to lower intertidal zones of a quiet water lagoon with low wave and tidal influences. The land-derived iron-rich colloidal suspensions are probably derived from the intensively lateritized hinterlands and the nearby surrounding emerged paleohighs of iron- and glaucony-bearing Cenomanian clastics of the Bahariya Formation. The lagoonal environment is developed in a tectonically-controlled low-lying area representing the downthrown side of the major NE-SW right lateral strike slip fault (Ghorabi-El Ghaziya fault). The bioturbation and mottling of these mud-ironstones and the presence of relics of glaucony facies support its deposition in slightly reducing to oxidizing condition and under quiet and low energy environment with low sedimentation rates (Mesaed and Surour, 2000). The manganese enrichment of the lower burrow-mottled mud-ironstones give more evidences on the deposition in near shore oxygenated lagoon or swamps (Stanton, 1972). The thinly laminated brick red hematitic mud-ironstone is marked by the presence of irregular fenestral cavities, rootlet molds and casts and desiccation cracks that indicate deposition under low tidal influences in the upper intertidal mud flat and exposed to subaerial processes (Reinson, 1992).

2. Stromatolitic Ironstone Facies (2 m thick)

This facies comprises the lowermost part of the lower ironstone sequence in the central sector and is equivalent to the mud-ironstone facies in the southern sector (Fig. 5, Plate 2A). It unconformably rests on the cross-bedded ferruginous sandstones of the Cenomanian Bahariya Formation. The lower part of this unit is build up of 30-60 cm thick stromatolitic mud-/wacke-ironstone facies grading upward into oncoidal rud-ironstone facies (Plate 2B). The stromatolitic mud-/wacke-ironstone facies consists mainly of brown amorphous iron oxyhydroxides and shows characteristic stromatolitic organo-sedimentary structures. Morphologically, the stromatolitic mud-/wacke-ironstone can be vertically differentiated into the following three morphotypes, being arranged from base to top as follow: oncolitic type, planar to wavy "stratiform" type, and micro-columnar "digitate" type (Plate 2D).

- The oncolitic type consists of irregular concentrically to semi-concentrically laminated bodies and forms the substrate for the next planar to wavy stratiform type. The shape and size of these oncoids depend on the shape and size of their nuclei. The nuclei consist of skeletal red and green algae, nummulite tests, peloids and angular mud-ironstone clasts. The oncoid cortical laminae are fitted vaguely with those of the neighboring grains. Microscopically, the oncoid cortical laminae contain a variety of filamentous and coccoid cyanobacteria. The matrix consists of dark brown amorphous iron oxyhydroxides and ferruginized skeletal particles with yellow isopachous goethite cement.
- The "stratiform" stromatolitic type consists of flat to wavy thin laminae and they contain fenestral cavities of laminoid and tubular forms. The lateral persistence of these laminae may be disrupted due to desiccation, folding and bioturbation. The stromatolitic laminae may overlap each other and exhibit tuft-like structures. Microscopically, these laminae show variable color intensities, from yellowish green amorphous iron oxyhydroxide laminae to brown goethitic laminae (Plate 2E).
- The micro-columnar "digitate" type (Aitken, 1967) grows as small fingers on the upper surface of the previous type. A number of small fingers are coalesced upward by the development of lateral linkage into more compound domal and columnar types (Plate 2F).

The oncoidal rud-ironstone facies (up to 1.5 m thick) consists of rounded to sub-rounded yellowish brown ferriferous oncoids (up to 0.7 cm in diameter), micro-oncoids (0.7-1.5 mm) and less frequent segments of oncoid cortices, showing grain-supported fabric (Plate 2G). The ferriferous oncoids have circular, ellipsoidal and amoeboidal shapes and posses nuclei of micro-oncoids and fragments of stromatolitic ironstone. The oncoid cortical laminae vary from even and wavy to crenulated types. These framework components are embedded in a reddish brown amorphous iron oxyhydroxide matrix that is partially to completely recrystallized into acicular goethite and hematite crystallites. The upper boundary of this oncolitic ironstone is highly desiccated and *in situ* brecciated. The XRF analyses of this facies are shown in Table 2.

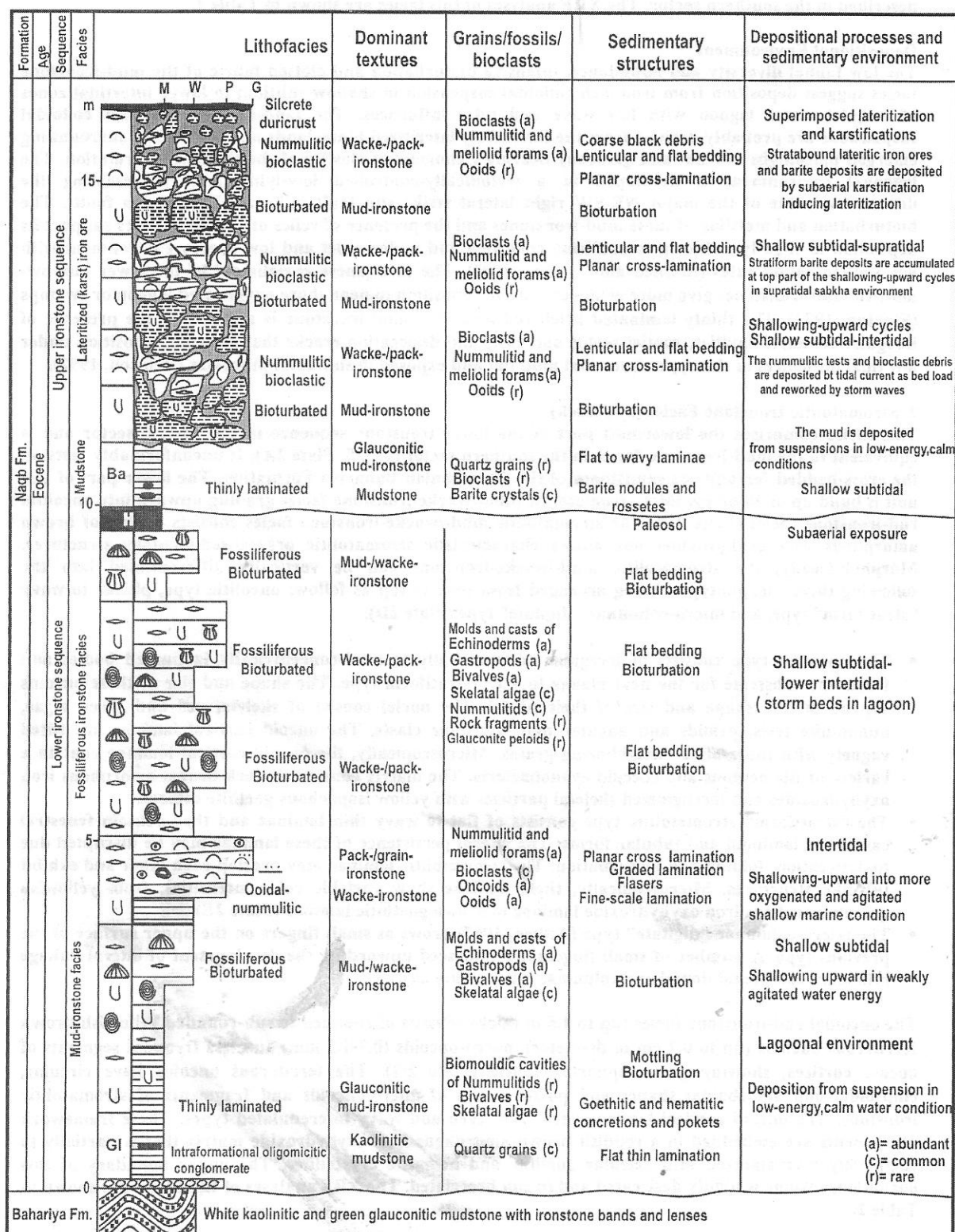


Fig.4. Facies analyses and depositional environments of the Eocene ironstones at the eastern part of the southern sector of Gabal Ghorabi mine areas (section 2, Fig.2).

Table 2. XRF analyses of the different ironstone microfacies of Gabal Ghorabi mine area.

I.S type	Mud-ironstone								
I.S sub-type	A-Yellow mud-ironstone			B-Goethitic	C-Mn-rich hematitic				
oxides	1	2	3	4	5	6	7	8	9
Fe	51.8	49.2	43.2	57.7	38.5	54.6	57.4	48.6	51.1
Cl	0.26	1.48	2.67	0.65	0.16	0.11	0.25	0.45	0.42
SiO ₂	7.03	11.09	6.22	4.76	14.9	0.72	1.01	0.86	5
MnO	1.56	0.75	0.85	0.39	8.59	9.92	10.14	8.96	5.79
BaO	0.07	0.56	2.4	0.08	0.49	0.22	0.8	1	0.86
Al ₂ O ₃	3.66	2.62	3.42	0.83	5.72	0.02	0.36	Nil	1.06
CaO	0.27	0.41	2.05	0.27	0.57	0.14	0.35	0.29	0.25
MgO	0.47	0.41	2.05	0.26	0.61	0.3	0.45	0.7	1.15
K ₂ O	0.29	0.06	0.13	0.13	0.99	0.04	0.04	0.1	0.11
P ₂ O ₅	0.32	0.31	0.69	0.24	0.3	0.23	0.3	0.1	0.17
S	0.12	0.41	0.14	0.11	0.22	0.06	0.17	0.16	Nil
TiO ₂	0.14	0.04	0.08	0.08	0.31	0.03	0.04	0.03	0.07

I.S type	E-Oolitic-oncolitic I.S		F-Nummulitic I.S			G-Fossiliferous I.S		H-Green mudstone	
oxides	11	12	13	14	15	16	17	18	19
Fe	52.6	46.5	55.3	28.4	57.8	50	54.7	9.04	9.2
Cl	1.51	1.32	0.22	7.18	0.55	0.3	0.36	4.9	5
SiO ₂	4.14	16.9	7.35	24.7	0.7	0.24	1.4	36.7	28.8
MnO	1.65	0.19	0.25	3.94	7.56	17.21	10.2	0.2	0.12
BaO	0.9	0.24	0.07	0.22	0.81	0.9	0.25	2.02	0.6
Al ₂ O ₃	1.97	1.68	1.4	0.32	0.08	0.16	0.84	16.5	14.7
CaO	0.54	0.34	0.82	0.64	0.39	0.21	0.26	1.06	0.21
MgO	0.54	0.34	0.29	0.64	0.7	0.8	0.62	2.17	1.3
K ₂ O	0.07	0.06	0.07	0.06	0.1	0.07	0.09	2.79	2.06
P ₂ O ₅	0.39	0.3	0.29	0.2	0.14	0.23	0.2	0.32	0.11
S	0.74	0.64	0.28	0.21	0.24	0.13	0.18	0.37	0.14
TiO ₂	0.04	0.02	0.06	0.03	0.03	0.02	0.04	1.17	0.92

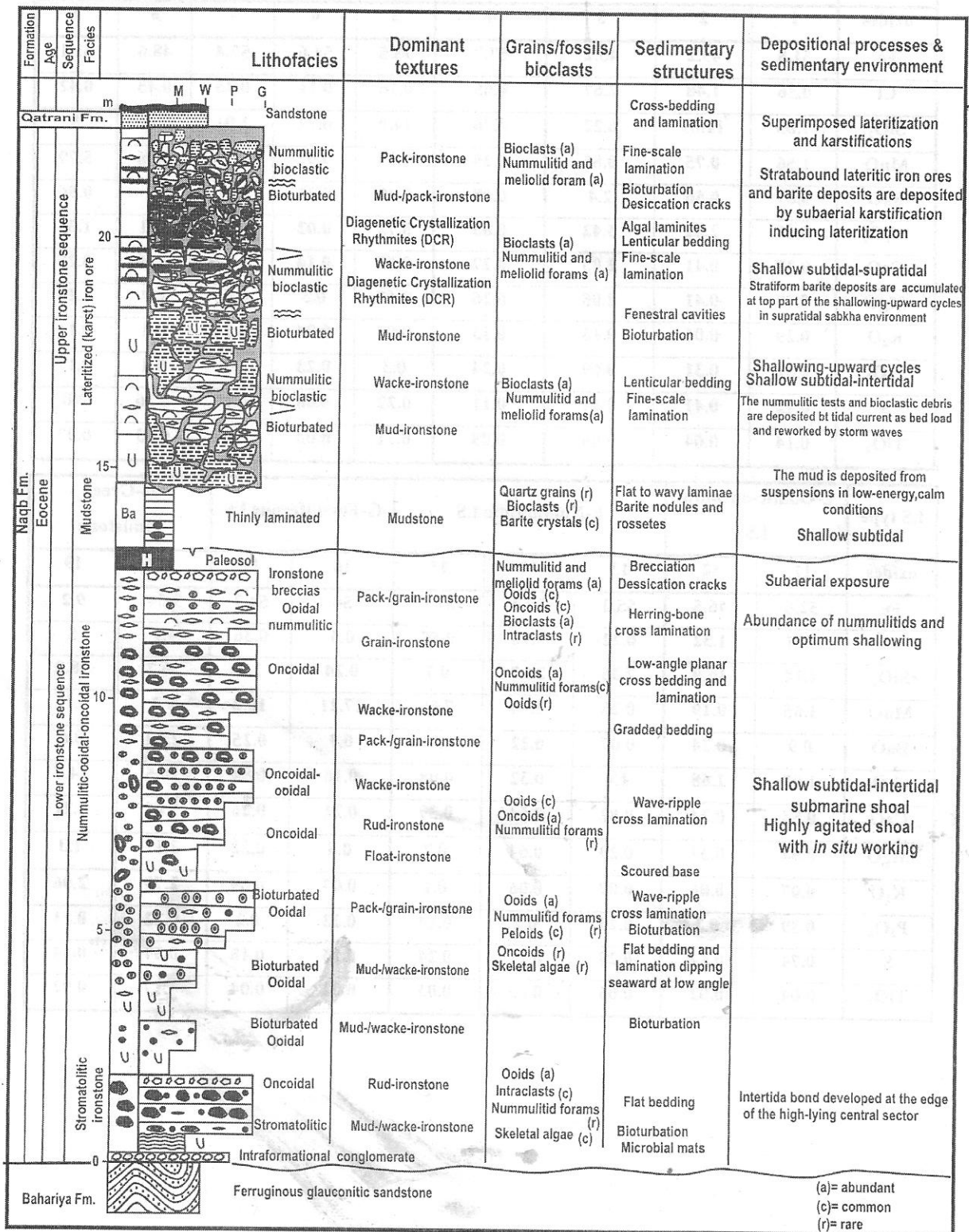


Fig.5. Facies analyses and depositional environments of the Eocene ironstones at the central sector of Gabal Ghorabi mine area (section 3, Fig.2).

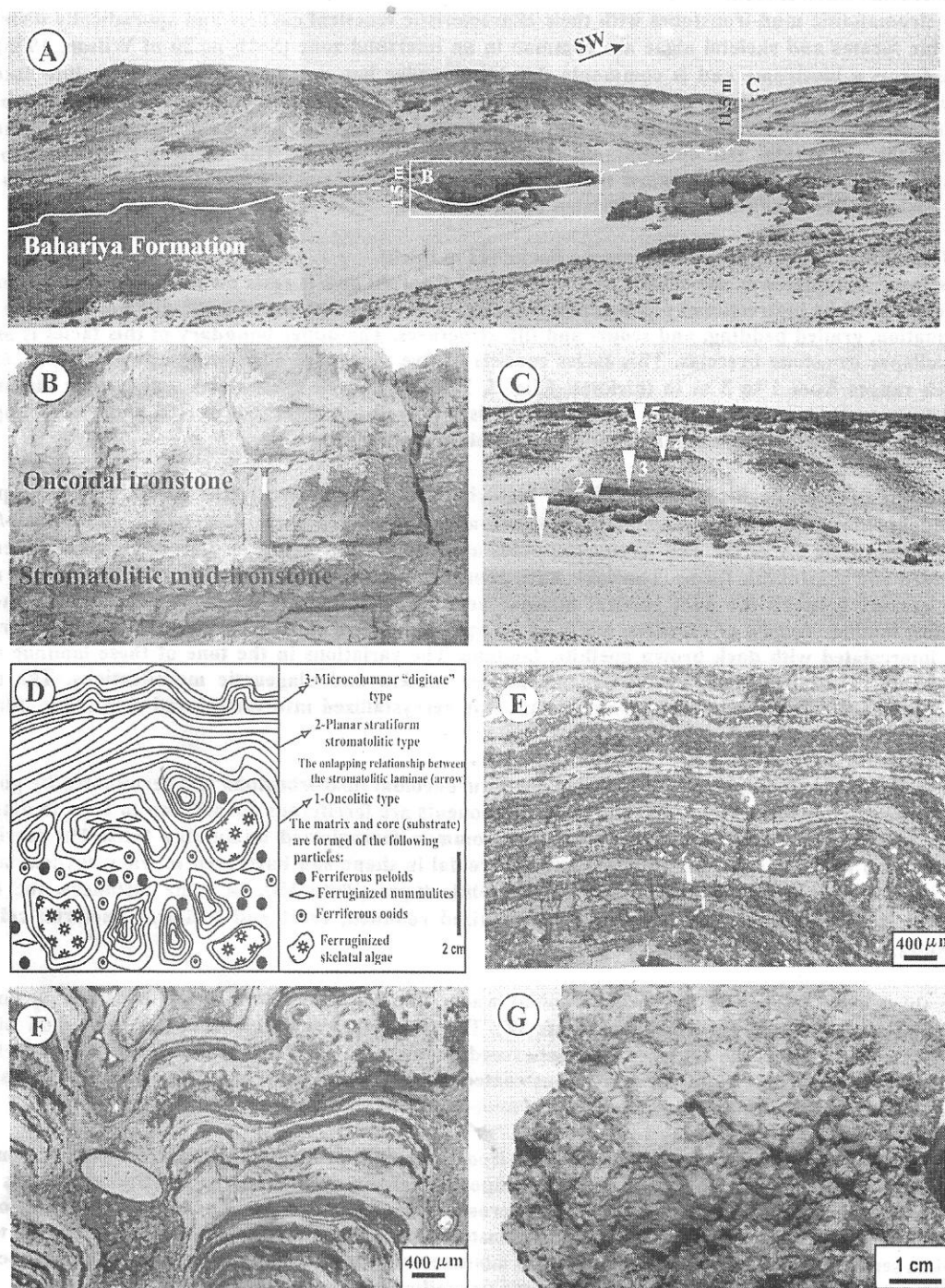


Plate 2. A) Panoramic field view of the lower ironstone sequence of the central sector of Gabal Ghorabi. This sequence onlaps and truncates the underlying Bahariya Formation and consists of stromatolitic mud-ironstone unit (C) and nummulitic-oolitic-oncolitic ironstone unit (D). Photo looking due southwest; B) The stromatolitic ironstone unit consists stromatolitic mud-ironstone grading upward into oncolitic ironstone; C) Field photograph showing the five coarsening-upward cycles constituting the nummulitic-oolitic-oncolitic ironstone unit of the central sector of Gabal Ghorabi mine area; D) Simplified sketch for the different morphologies of the stromatolitic mud-ironstone: 1- oncolitic type, 2- planar stratiform stromatolitic type, and microcolumnar "digitate" type; E) Planar stratiform stromatolitic mud-ironstones showing different colour and mineralogical variations, PPL; F) Microcolumnar "digitate" stromatolitic type grows as surface irregularities on the upper surface of the previous type. Notice the presence of ferriferous peloids within the intercolumnar areas, PPL. (G) The oncoloidal float-/rud-ironstone consists of large yellowish brown ferriferous oncoids embedded in brick red hematitic matrix. PPL. = Plane Polarized Light

Depositional Environment

The stromatolitic mud-ironstones with their characteristic fenestral cavities and sporadically distributed benthic forams and skeletal algae are common in an intertidal zone (SMF no.20 of Wilson, 1975). This type forms a biostrome and is commonly developed under low energy conditions in shallow intertidal environment (Gerdes *et al.*, 1994). The close associations of the ferriferous micro-oncoids and oncoids within the laminated stromatolitic mats may indicate that these grains are *in situ* formed (autochthonous) within the same tidal flat environment (Dahanayake *et al.*, 1985). The vertical transition from the stromatolitic mud-ironstone toward the oncoidal ironstone may suggest shallowing-upward from calm, low-energy water condition toward agitated water condition.

3. Nummulitic-Ooidal-Oncoidal Ironstone Facies (11 m thick)

This facies dominates in the central sector of Gabal Ghorabi and it rests on the stromatolitic ironstone facies. It exhibits bidirectional planar cross-beddings with a general dip of 5-10° due north, ripple cross-lamination, graded bedding, and scour- and fill- structures. The upper boundary of this facies is marked by collapse ironstone breccias. This facies consists of five successive shallowing-upward cycles, each of which ranges from 1 to 3 m in thickness (Fig. 5, Plate 2C). Each cycle starts with yellow bioturbated matrix-supported mud-ironstones passing upwards into well to moderately sorted and grain-supported ooidal, peloidal, oncoidal and nummulitic pack-/grain-ironstones.

The lower cycle (1) begins by an egg-yellow bioturbated massive to faintly laminated, matrix-supported, peloidal-ooidal mud-/wacke-ironstones and terminated by silicified goethitic peloidal-ooidal pack-/grain-ironstones (Plate 3A & B). The ferriferous ooids and peloids (0.5-2 mm in diameter) are of spheroidal, rounded and spastolithic forms. The ooids have poorly developed cortical laminae with less distinct nuclei. The contact between the ooid cortical laminae and the surrounding matrix is gradational. The ooid cortical laminae consist of couplets, made up of egg-yellow glauconitic clay laminae with faint greenish tint intercalated with dark brown goethitic laminae. The variations in the tone of these laminae can be attributed to the difference in the organic matter content and diagenetic modifications. The matrix consists of amorphous iron oxyhydroxide, commonly recrystallized into varicolored crystalline phases of goethite, hematite and pyrolusite.

The second cycle (2) begins by bioturbated goethitic oncoidal float-ironstone and terminated by goethitic oncoidal rud-ironstone (Plate 3C). The main components are ferriferous oncoids, up to 1 cm in diameter, micro-oncoids (0.5-2 mm in diameter) and less common ferruginized nummulite tests. The ferriferous oncoids and micro-oncoids are rounded and spheroidal in shape and have even to wavy cortical laminae that may evolve into club-shaped microstromatolitic types (Plate 3D). In some instances, the oncoid cortical laminae may entirely consist of ferruginized rounded, erect and fusiform bacterial cells and capsules.

The third cycle (3) begins by oncoidal-ooidal wacke-ironstones and terminated by silicified goethitic oncoidal-ooidal pack-/grain-ironstones (Plate 3E). The framework components of this cycle show bimodal grain size distribution, the ooid size does not exceed 2 mm in diameter and the oncoid size exceeds 0.5 cm in diameter. The majority of the ferriferous-coated grains lack cores (Plate 3F), while few grains have cores made up of nummulite tests and angular mud-ironstone clasts.

The fourth cycle (4) begins by oncoidal wacke-ironstones and terminated by silicified goethitic oncoidal grain-ironstones (Plate 3G). The framework components of this cycle comprise ferriferous oncoids (up to 0.5 cm in their diameter) mixed with few ferriferous ooids and intraclasts. The majority of these oncoids have cores made up of angular massive mud-ironstone clasts (Plate 3H), fragments of nummulite tests or broken segments of oncoid cortex. The cortical laminae are even to slightly wavy and well developed. The allochemical components are cemented by micro-crystalline mosaic quartz.

The fifth cycle (5) begins by ooidal-nummulitic wacke-ironstones grading upward into silicified goethitic ooidal-nummulitic pack-/grain-ironstones. The framework components consist of ferruginized and silicified microbored skeletal particles admixed with few scattered ferriferous ooids, oncoids and peloids. The main skeletal components are nummulites associated with body fossils and bioclasts of echinoid plates, spines and skeletal algae (Plate 3I). The skeletal particles and the ferriferous ooids are arranged in repeated thinly cross-laminated couplets that show graded patterns. Each couplet consists of rhythmically alternated fine-grained and well-sorted peloids and ooids with nummulitic cores and coarse-grained and moderately sorted nummulite tests, bioclastic debris

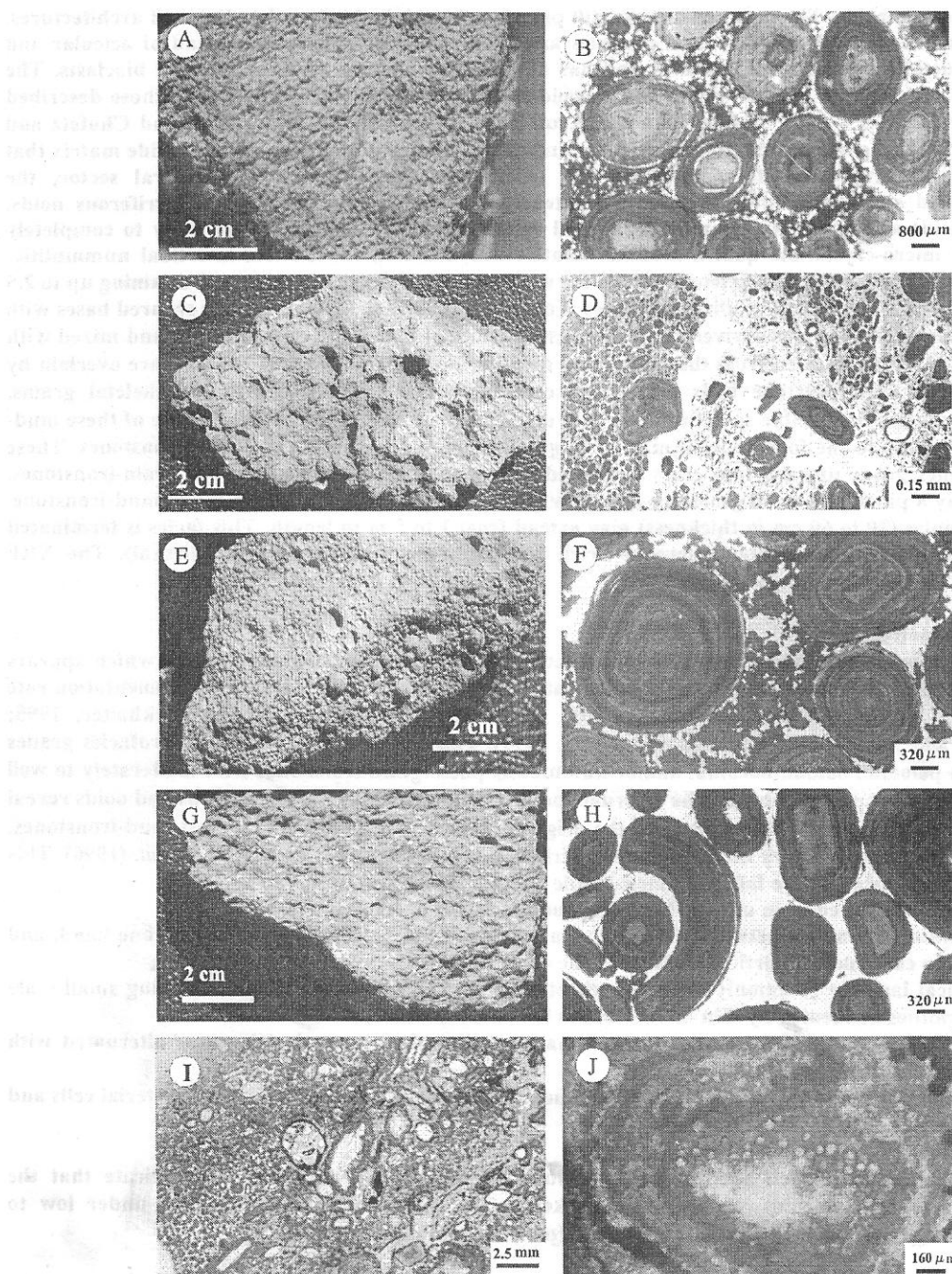


Plate 3. A) Hand sample showing well sorted and grain-supported silicified ooidal ironstone (top of the first shallowing-upward cycle). (B) Well sorted ooids and peloids embedded in brown organic-rich amorphous iron oxyhydroxide matrix, PPL. (C) Oncoidal rud-ironstone (top of the second shallowing-upward cycle). (D) Microscopic scoured contact between the well sorted ooidal ironstones and the overlying oncoidal float-/rud-ironstones, O.L. (E) Moderately sorted and grain-supported oncoidal-ooidal ironstone forming the top of the third shallowing-upward cycle. (F) Yellowish brown ferriferrous oncoids embedded in mottled and amoeboidal recrystallized goethite matrix. Notice the absence of obvious core, PPL. (G) Well sorted and grain-supported oncoidal grain-ironstone terminating the fourth shallowing-upward cycle. (H) Well sorted with core made up of angular mud-ironstone clasts. Notice the presence of spastolithic ooids with half moon-like shape, PPL. (I) Ooidal-nummulitic grain-ironstone terminating the uppermost shallowing-upward cycle. Notice the ripple cross-lamination and graded lamination, O.L. (J) Rounded single and bilobed coccoid cyanobacterial cells embedded in glauconitic clays and egg-yellow and brown amorphous iron oxyhydroxides matrix.

PPL. = Plane Polarized Light O.L. = Ordinary Light

and ferriferous oncoids. The nummulite tests still preserve the original internal radial wall architectures. The ferruginized skeletal and bioclastic particles are often coated by thin massive rind of acicular and polygonal goethite crystals. The goethite rind has an irregular contact with the internal bioclasts. The cortical laminae are rich in filamentous and coccoid cyanobacteria (Plate 3J), similar to those described by Dahanayake *et al.* (1985); Dahanayake and Krumbein (1986); Chafetz *et al.* (1998) and Chafetz and Guidry (1999). These framework components are embedded in amorphous iron oxyhydroxide matrix that is subjected to progressive ferruginization and silicification. Westwards in the central sector, the aforementioned shallowing-upward cycles are intensively silicified. The framework ferriferous ooids, peloids, oncoids and bioclastic components as well as the interstitial matrix are partially to completely replaced by micro-crystalline quartz mosaics. Southwards, the shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstone facies extends toward the western part of the southern sector, attaining up to 2.5 m in thickness (Fig. 3). In this locality, this facies is characterized by sharp and erosive scoured bases with ooidal-oncoidal ironstone lags derived from the crest of the tidal bar of the central sector and mixed with coarse skeletal debris derived from the underlying fossiliferous ironstone facies. The lags are overlain by burrow-mottled mud-ironstone beds and lenses containing few sparsely distributed skeletal grains. Ferriferous oncoids of variable sizes (up to 6 cm in diameters) are developed at the expense of these mud-ironstones, leading to the formation of matrix- to grain-supported oncoidal float-/rud- ironstones. These mud-ironstones grade upward into cross-laminated megaripples of ooidal-nummulitic grain-ironstones, which display a pinch and swell geometry and their troughs are filled by burrow-mottled mud-ironstone. The megaripples (20 to 60 cm in thickness) may extend from 1 to 5 m in length. This facies is terminated by thinly laminated and highly desiccated brick red hematitic mud-ironstones (paleosol). The XRF analyses of this facies are shown in Table 2.

Depositional environment

The cyclic pattern of this facies start with bioturbated mud-/wacke-ironstone microfacies, which appears to be deposited from suspension in relatively quiet water, low-energy condition with low sedimentation rate as confirmed by the intensive bioturbation and clastic starvation (Young, 1989; Burkhalter, 1995; Macquaker and Taylor, 1996 and Donaldson *et al.* 1999). The mud-/wacke-ironstone microfacies grades upward into peloidal, ooidal, oncoidal and/or nummulitic pack-/grain-ironstones with moderately to well sorted and grain-supported fabrics. The external and internal morphology of the oncoids and ooids reveal *in situ* biogenic accretion at the expense of the original Fe-rich precipitates of the host mud-ironstones, similar to the intrasedimentary accreted ooids described by Guerrak (1987) and El Aref *et al.* (1996). This conclusion is supported by the following megascopic and microscopical observations:

1. The absence of true cores in most of the ferriferous oncoids and micro-oncoids,
2. The gradational contacts between the cortical laminae and the surrounding matrix on one hand, and between the core and the cortical laminae on the other hand,
3. The cortical laminae commonly overlap each other and exhibit swelling nature, forming small-scale disconformities delineated by thin discontinuous hematitic laminae,
4. The occurrence of discontinuous and non-isopachous thrombolitic cortical laminae alternated with even stromatolitic laminae, and
5. The abundant distribution of microbial forms such as filamentous and coccoid cyanobacterial cells and capsules within the ferriferous oncoids.

The textural parameters and sedimentary structures of the pack-/grain-ironstones indicate that the ferriferous ooids and oncoids are *in situ* reworked in a shallow marine environment under low to moderate energy conditions at or above wave base (para-autochthonous grains).

The ferriferous ooids and oncoids capping the uppermost two shallowing-upward cycles are cored by angular segments of broken ooids, ironstone clasts as well as ferruginized foraminiferal tests and bioclasts of various megafossils. The cortical laminae have sharp contacts with the central cores and may exhibit highly contorted and microstromatolitic shapes. The well sorted textures and grain-supported fabrics indicate *in situ* reworking of the mud fraction with low to moderate energy by tidal and/or storm current and waves at/or above wave base. The ooid and oncoid cortical laminae are most probably formed during the calm inter-storm periods, where they are colonized by a variety of microscopic (microbial) organisms.

The faunal assemblages increase in abundance with the upward shoaling and this indicate open and normal marine conditions (Wilson, 1975 and Maynard, 1983). The nummulites have originally lived on a relatively soft muddy substrate (Girgis and Hindy, 1973) and the good conditions for their development are warm, well oxygenated water (Blondeu, 1972). The nummulite tests and bioclastic debris appear to be transported as a bedload during periods of high velocity, producing sheets or megarippled bedforms. The

moderately to well sorted textures and the grain-supported fabrics of these fossil allochems and the associated ferriferous ooids, peloids and oncoids together with their concentration in a megarippled bedforms indicate *in situ* reworking and redeposition with winnowing of the mud constituents. They can be described as parautochthonous grains (Kidwell and Holland, 1991).

During the intermittent periods (inter-storm events) of low velocity, the iron-rich fine materials are settled down from suspension as confirmed by the presence of burrowing effects, iron-encrusting organisms and ferruginous bored bioclasts (Burkhalter, 1995). The suspended iron-rich materials are infiltrated and adsorbed into the inter- and intra-skeletal pore spaces that are assisted by microboring organisms. The original calcareous fossil particles are replaced by amorphous iron oxyhydroxides. These ferruginized fossil lags provide a mobile substrate for iron-encrusting organisms to develop ferriferous ooids and oncoids. Such conditions of quiet water energy and development of iron-encrusting organisms are favourable for developing microstromatolitic cortical laminae surrounding cores of ferruginized nummulite tests and bioclastic grains and mud-ironstone clasts. These favourable conditions of prolific development, *in situ* concentration and reworking of the nummulite tests are predominated in shallow subtidal-intertidal shoals, tidal bars and tidal channels (Wilson, 1975), which are subjected to episodic storm waves (Blondeu, 1972; Aigner, 1984). The uppermost part of this shoal is entirely built up of nummulitic ironstone that is subjected to storm-generated erosion, reworking, winnowing during relative sea level fall (Cotter and Link, 1993). These storm beds become exposed to subaerial weathering and pedogenic processes. The net result is a typical shallowing-upward sequence and seaward progradation of the shoreline. This tidal bar or shoal is built up on a submarine swell of the underlying Cenomanian Bahariya Formation.

The southward extension of the shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstone facies indicates that the tidal bar crest is dissected by tidal channel that extends lagoonward during the storm event and truncates the underlying shallow subtidal-lower intertidal lagoonal fossiliferous ironstone facies.

4. Fossiliferous Ironstone Facies

This unit is well developed in the southern sector of Gabal Ghorabi mine area, attaining up to 6 m in thickness. The upper surface of this facies is highly bioturbated and brecciated and exhibits symmetrical wave-generated ripples, while the lower surface is sharp and erosive with a variety of sole structures. It is composed of successive coarsening-upward cycles, showing a general upward trend of graded bedding. The coarsening-upward successions are well represented in the eastern part of the southern sector of Gabal Ghorabi mine area, comprising four cycles of up to 6 m thick and terminated by brick red hematitic mud-ironstone (section. 1, Fig. 3 and section. 2, Fig. 4). Each cycle (1 m thick) starts with egg-yellow mottled and/or thinly laminated stromatolitic mud-ironstone, commonly oxidized into dark violet to black hematitic massive mud-ironstone varieties. It grades upward into storm beds of variable internal fabrics and textures represented by highly bioturbated, fossiliferous ironstones of matrix- or grain-supported float-/rud-ironstone or wacke- to pack-ironstone microfacies. The allochemical components of these microfacies include abundant bioturbated hematitized fossil molds and casts with less frequent glauconitic and barite cemented sandstone lithoclasts.

The faunal assemblage includes, in order of abundance, echinoid plates and spines, bivalves, gastropods, skeletal algae and benthic large forams, mainly nummulitids. Toward the western part of the southern sector, this facies is reduced in thickness into 3 m thick and is truncated by megaripples and lenses of nummulitic-oidal-oncoidal ironstones. Said and Issawi (1964) identified the following fossil content in this unit: *Corbis lamellose*, *Corbula aff. galica*, *Spondylus aegyptiacus*, *Velates schmiedeli*, *Turritella Sp.*, *Cerithium Sp.*, *Cytherea Sp.*, *Bulla laevissima*, *Nerita affinis*, *Natica longa*, *Diplodonta rotunda*, *Macrosolen uniradiatus*, *Cassia nilotica*, *Crepidula cossmanni*, *Turbinella Sp.*, *Gastrochaena Sp.*, *Cardita Sp.*, *Nummulites atacicus*, *N. subramondi*, *Assilina praespira*, *Discocyclus Sp.*, *Operculina discoidea*, and *Alveolina frumentiformis*. The XRF analyses of this facies are shown in Table 2.

Depositional Environment

The cyclic pattern of the fossiliferous ironstone facies indicates shallowing upward tendency from the low energy, quiet water conditions dominated during the deposition of the mud-ironstone part of each cycle. Meanwhile, the upper part of these cycles reflects agitated water condition dominated during the intermittent storm events. The fossil assemblage of these beds indicates that they are derived from open and normal shallow marine areas (Wilson, 1975). The accumulation, sorting and restriction of these enormous fossil assemblages in the southern sector appear to be formed under high-energy condition by

storm waves and currents at/or above storm wave base during periods of relative sea level fall (Cotter and Link, 1993). The first stage of this storm event is the storm erosion and reworking of the skeletal grains as a bed load associated with fine-grained iron-rich muddy sediments as a suspended load. The good preservation of the shells suggests that reworking of the skeletal particles are "near *situ*" or "parautochthonous" sensu Kidwell and Holland (1991). During the waning stage of the storm, as the storm decreases in intensity, the reworked skeletal grains are settled down to form winnowed shell lags over a basinal erosional surface (Kreisa and Bambach, 1982). The fine-grained suspended iron-rich sediments are infiltrated and percolated down into the lag, filling inter- and intra- skeletal pore spaces and gradually replace the original calcareous wall structures of the shell lags. Post-storm deformation is indicated by bioturbation that destroyed most of the primary sedimentary structures.

5- Nummulitic Ironstone Facies (6 m in thickness)

This facies represents the northward lateral facies change of the shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstone facies of the central sector. It is formed of four shallowing-upward cycles; each cycle begins by burrow-mottled Mn-rich nummulitic mud-ironstone (Fig. 6, Table 2) and is terminated by yellowish brown to black ooidal and/or nummulitic wacke- to grain-ironstone microfacies. It also contains varieties of ferruginized molds and casts of various mega- and micro-fossils, forming fossiliferous wacke-/pack-ironstones. This facies exhibits low-angle planar and trough cross-lamination, ripple cross-lamination, parallel lamination and thin mud-ironstone flasers. The succeeding coarsening-upward cycles are of reddish brown to black in color as a result of their manganese enrichment and are highly bioturbated. It is terminated by bioturbated nummulitic pack-ironstone rich in nummulite biomouldic cavities. The nummulitic ironstone facies is terminated by brick red hematitic mud-ironstone horizon, which can be traced all over Gabal Ghorabi area. The XRF analyses of this facies are shown in Table 2.

Depositional Environment

The cyclic nature of this facies suggests deposition under shallowing-upward condition of shallow subtidal environment. The local accumulations and *in situ* reworking of the ferruginized nummulite tests together with the lenticular and megarippled bedforms may indicate the role of storm currents in the concentration of these fossil allochems. The transition from the underlying shallow subtidal-intertidal ooidal-nummulitic ironstones facies into the bioturbated nummulitic ironstone facies indicates a return into a relatively deep, low-energy and quiet water condition (Tucker and Wright, 1990).

B-The Upper Ironstone Sequence

1-Olive green mudstone Facies (~1m thick)

This facies represents a marker stratigraphic horizon of almost constant thickness and can be traced all over Gabal Ghorabi mine area and the surrounding carbonate scarp. It unconformably rests on the underlying paleosol horizon, capping the lower ironstone sequence (Plate 4A). In its lower part, the mudstone facies consists of thinly laminated fissile olive green to greyish white kaolinitic mudstones. It grades laterally and vertically into thin bioturbated egg-yellow glauconitic mud-ironstones, containing goethite nodules. Different forms and sizes of septarian barite nodules and rosettes (0.5-3 cm in diameter) are sparsely distributed throughout the kaolinitic mudstones (Plate 4B). Such nodules have spherical to slightly elongated, Potato-like and cauliflower-like shapes with smooth or rough external outlines. The barite nodules of the northern sector are well developed and may reach up to 15 cm in thickness. Most of these nodules are usually of flat, irregular and contorted shapes whereas other nodules have lenticular shapes with smooth or rough external outlines. The growth of these barite nodules displaces the host kaolinitic mudstone and the long axes follow the bedding planes. Microscopically, the olive green mudstones consist of glauconitic and kaolinitic clays with randomly distributed rounded to sub-rounded authigenic patches and pockets of kaolinite booklets (Plate 4C). Idiomorphic to hypidiomorphic individual barite crystals as well as barite rosettes and nodules are disseminated without following the planar structure of their host mudstone. Few scattered quartz grains are associated within the mudstone. The XRF analyses of this facies are shown in Table 2.

2- Nummulitic-Bioclastic Ironstone facies

This facies represents the original marine ironstone facies of the lateritized iron ore unit and it consists of three repeated shallowing-upward cycles; each cycle begins by thinly laminated or burrow-mottled glauconitic mud-ironstone and followed by nummulitic-bioclastic wacke-/pack-ironstone. Thin beds of stratiform barite terminate these cycles, especially in the central sector around the main NE-SW Ghorabi-El Ghaziya master fault. The microscopic examinations of this ironstone facies revealed the presence of the following microfacies, being arranged from base to top as follows:

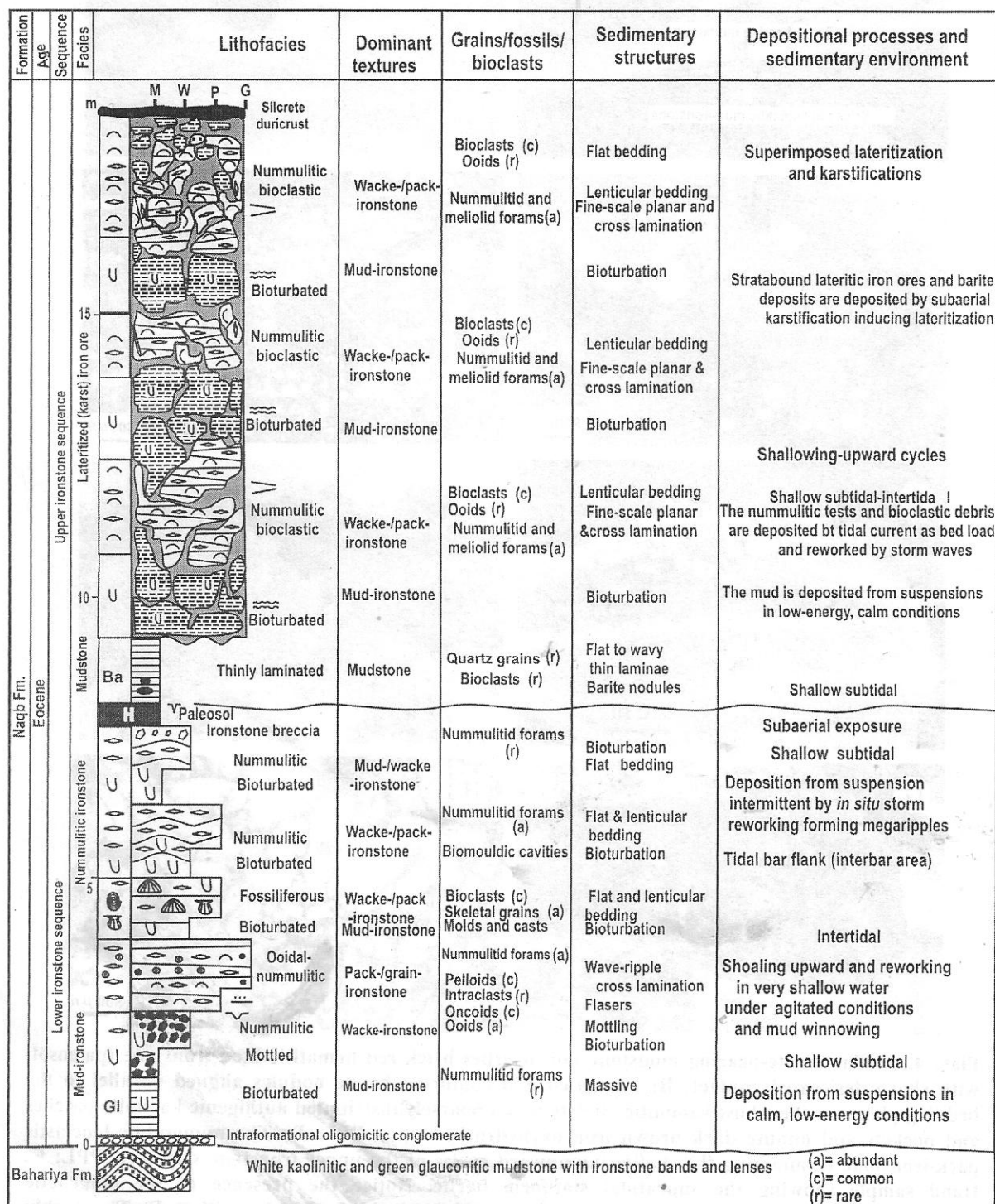


Fig.6. Facies analyses and depositional environments of the Eocene ironstones at the northern sector of Gabal Ghorabi mine area (section 4; Fig.2).

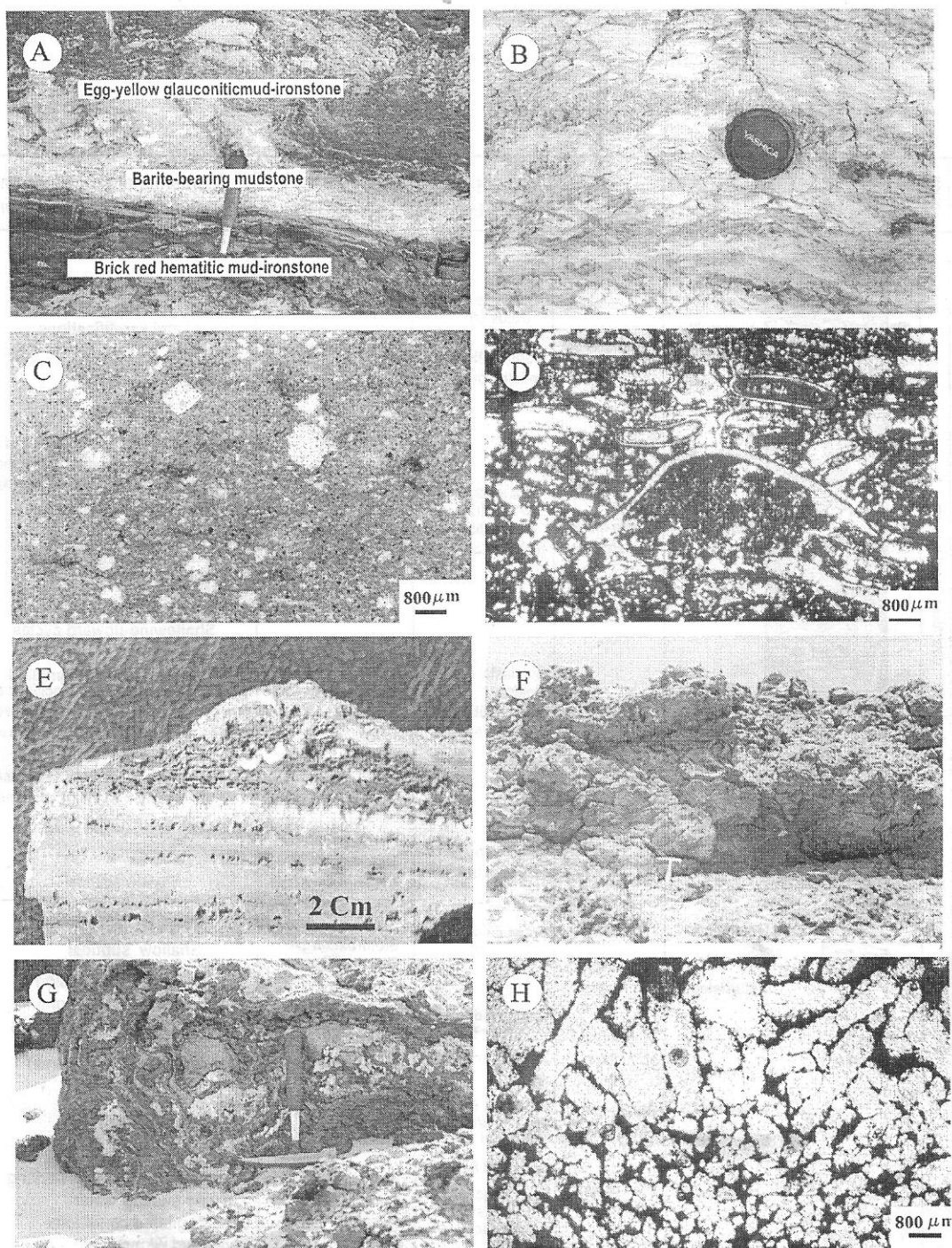


Plate 4. A) The barite-bearing mudstone unit overlies brick red hematitic mud-ironstone (paleosol) with sharp desiccated contact; B) Elongated and contorted barite nodules aligned parallel to the bedding planes of their host kaolinitic mudstone; C) Sparsely distributed authigenic kaolinite patches and pockets and minute dark brown iron oxyhydroxides spot, PPL; D) The nummulitic-bioclastis pack-ironstone terminating the shallowing-upward cycles of the upper ironstone sequence, PPL; E) Hand sample showing the supratidal statiform barite. Notice the presence of the diagenetic crystallization rhythmites "DCRs" and irregular and laminoid fenestral cavities; F) The highly brecciated ironstones with dissolution joints and cracks. Note that the bedding nature of the original ironstone facies is still preserved; G) Cockade structure consists of crustified layers of colloform goethite surround a core of the original bed rock; H) Different sizes of barite crystals with interstitial iron-rich infiltrated soil clays, PPL.
PPL. = Plane Polarized Light

- **Bioturbated mud-ironstone**

It is similar to the yellow mud-ironstone in the central sector and consists of massive to faintly laminated yellow amorphous iron oxyhydroxides mixed with ultra-fine goethite blotches and relicts of greenish yellow glauconitic clays.

- **Nummulitic-bioclastic wacke-/pack-ironstone**

This microfacies forms hard persistent and ledge-forming beds that thickens at the expense of the underlying mud-ironstones. It exhibits planar cross-lamination, small-scale wave-ripples and scour- and fill-structures. The main allochemical components include ferruginized and silicified bioclasts and nummulites (Plate 4D). These are enveloped by thin cortical laminae forming superficial ooids. The allochemical components are filled and embedded in a faint yellow to dark brown goethitic clay matrix. The matrix and allochemical components are partially to completely replaced by micro-crystalline quartz and calcedony. Secondary blocky calcite and barite crystals are also observed.

- **Supratidal (sabkha-related) stratiform barite**

This barite type terminates the shallowing-upward cycles and it shows a well-defined stratiform bedding nature. The megascopic observations of the oriented polished slabs of this type revealed the presence of the following features: a) rhythmic banding and lamination of varicoloured layers and laminae. These rhythmic bands are composed of silt to sand-sized barite-bearing mud laminae and micro- to coarsely crystalline barite laminae, b) laminoid fenestral cavities developed in dark, organic-rich laminae, particularly in cryptalgal laminites and they are often arranged parallel to the laminations, c) desiccation cracks, commonly filled with leached and illuviated silty materials, d) the presence of cryptalgal laminites, e) the presence of tepee structures, and f) the presence of Diagenetic Crystallization Rhythmites (Plate 4E), DCRs (Fontboté and Amstutz, 1980, El Aref, 1984 and El Aref and Ahmed, 1986). Microscopically, the rhythmicity of the diagenetic crystallization rhythmites (DCRs) is mainly related to the repetition of three geometric zones, which are corresponding to three generations of crystallization, i.e. I, II and III. Generation (I) represents the "starting sheet" for the development of the coarser generations II and III and it usually contains traces of poorly developed stromatolitic laminae. Generation (II) follows generation I and consists of medium to coarse subhedral to euhedral zoned and twinned barite crystals that are arranged in a bipolar pattern, growing above and below the "the starting sheet" or generation I. Generation (III) is represented by the remaining central spaces left behind generation II and commonly filled with blocky calcite or residual iron and manganese oxyhydroxides.

Depositional Environment

The deposition of the lower ironstone sequence consumes the paleotopography of the underlying Cenomanian Bahariya Formation and the upper surface of this sequence is a subaerially exposed peneplained surface. The deposition of the green mudstone facies on the paleosol surface is an abrupt change in facies and may suggest that the study area was drowned by a new marine transgression accompanied with rapid deepening. These mudstones are deposited from suspension in a relatively shallow subtidal basinal area with a low-energy, anaerobic to dysaerobic condition below wave base (Sageman *et al.* 1991). During the gradual upward shoaling, the prevailed physico-chemical conditions and depositional parameters are changed from suspended to bedload deposition. The bedload deposition is less efficient in dispersing sediments than suspended load, so that the nummulitic-bioclastic ironstones are restricted in megaripple structures rather than extensive sheets. The repetition of these shallowing-upward cycles indicates short periods of sea level fluctuation during transgressive-regressive events. The megascopic and microscopic observations argue for the diagenetic origin of the barite nodules and their growth within the mudstone facies during the diagenetic segregation and differentiation. The Diagenetic Crystallization Rhythmites are recorded in shallow water facies horizons, mainly tidal flats facies (Fuchs, 1984) or in karstic fillings. They appear to be deposited in local restricted evaporitic tidal ponds, distributed in patches along the high central sector. These textural and petrographical characteristics testify deposition in supratidal environment at the end of the shallowing upward cycles.

Lateralization (Karstification) of the Upper Ironstone Sequence and the Associated Barite Deposits

The superimposed subaerial lateritic weathering and pedogenic processes are responsible for the partial or complete destruction and brecciation of the original marine ironstone facies of the upper ironstone sequence. As a result of lateritization (karstification) processes, network of vertical and inclined solution channels and small to large-scale cavities are formed. Solution channels appear to be developed during surface water infiltration into joints communicating with lateral subsurface solution openings. The solution cavities range from small openings of few centimeters in diameter to large caves measuring

several meters in diameters. The internal walls of these cavities are lined by crustified-banded iron oxides, which are composed of rhythmic alternations of soft yellow and hard brown layers, up to 10 cm in thickness. The yellow layers are consisted of ochreous sediments and detrital silty quartz grains. The hard brown layers consist of fine radially goethite with or without hematite and pyrolusite crystals of colloform outlines and forming a megascopic botryoidal texture and spherulites. The formation of these colloform and/or botryoidal goethite and hematite forms suggests deposition from colloidal or supersaturated solution under favorable acidic to neutral conditions (El Aref and Loffy, 1989; El Aref, 1994 and El Aref *et al.* 1999). Collapse ironstone breccia fragments of variable sizes are formed throughout the gradual detachment along the fractures and the dissolution joints (Plate 4F). These collapse breccia fragments are composed of the original muddy and nummulitic ironstone facies, which commonly still preserving the original bedding nature of the upper ironstone sequence. Folded and contorted rhythmic layers of colloform goethite forming cockade structures surround these collapse breccias (Plate 4G). Geomorphologically, it forms small isolated irregular cone hills of 50-100 m in diameter and 4-12 m in height. The lateritic iron ore contains stratabound karst-related barite deposits. These deposits form large irregular masses and pockets of very coarse-grained, euhedral barite crystals cutting across the bedding planes of the mud- and nummulitic-bioclastic-ironstone facies and the associated stratiform barite. Secondary barite crystals cementing the collapse ironstone breccia fragments. The barite cement is associated with the secondary illuviated and infiltrated amorphous iron oxyhydroxides (Plate 4H), silica, and blocky calcite with or without halite, gypsum and anhydrite crystals.

DISCUSSION AND GENETIC MODEL

A genetic model for the ironstone formation was deduced from the stratigraphic relationships, structural elements and depositional facies and microfacies associations and their depositional environment. The facies analyses of the Eocene ironstone sequences were correlated with the equivalent carbonate succession of the surrounding nearby plateau (Fig. 7).

The different depositional stages of ironstone and carbonate formation can be summarized as follows:

1. Since Late Cretaceous time, the Ghorabi paleohigh was tectonically standing as positive block or swell area and subjected to intensive denudation and pedogenesis (Said, 1990; El Aref *et al.* 1999 and Helba *et al.* 2001). This swell was dissected by active NE-oriented normal fault system during Cretaceous time and reactivated as right lateral strike-slip faulting during the Eocene time (Sehim, 1993; IEP, 1993-1997 and Moustafa *et al.* 2003). This fault system dissects the Ghorabi paleohigh into three sectors, the southern and northern sector were topographically low-lying areas, while the central sector was a topographically high area (Fig. 8A). At the beginning of the Eocene time, the sea drowned the Ghorabi, El Gedida and El Harra paleohighs and as a consequence a ramp setting for the carbonate deposition was developed but with isolated submarine swells of double plunging anticlines. These swells are formed of Cenomanian clastics of the Bahariya Formation and enclosing glauconitic ironstone lenses and bands (Helba *et al.* 2001 and El Aref *et al.* 2001).
2. During the early depositional stages, semi-restricted lagoon was developed in the low-lying southern sector and open shallow subtidal environment was developed in the low-lying northern sector. The central sector and other surrounding paleohighs of the Cenomanian Bahariya Formation were most probably still emerged, forming shallow tidal flats (Fig. 8B). Upon these emerged tidal flats, iron-rich colloidal materials were leached from the Cenomanian clastics and debauched into the low-lying areas (ironstone type 2 of El Aref *et al.* 1999). These iron and organic - rich colloidal materials were redeposited from suspension in calm water energy, forming the mud-ironstone facies that may contain few scattered ferruginized nummulite tests in the northern sector. In the mean time, further northwards, a thick bioturbated bioclastic nummulitic limestone unit was deposited in more open shallow subtidal environment under clam condition but interrupted by intermittent storm events.
3. With advance and rise of the Eocene sea level, the entire area is completely drowned by water and the ramp setting became ecologically a favourable habitat for the prolific growth of the large benthic foraminifera. These forams, in addition to pelecypods, gastropods, echinoderms and skeletal algae, thrive on shallow oligotrophic carbonate platform. In the subtidal low-lying areas, different ironstone facies were accumulated in the different sectors depending on the water hydrodynamics and the paleotopography. On contrary, the submarine paleohigh of the central sector is dominated by shallow subtidal-intertidal nummulitic-oidol-oncoidal ironstones, arranged in five shallowing-upward cycles of variable thicknesses. The variation in thickness is attributed to the effect of pre- and syn-tectonic minor block faulting deduced from the thickness map. With a gradual-upward shoaling, the large

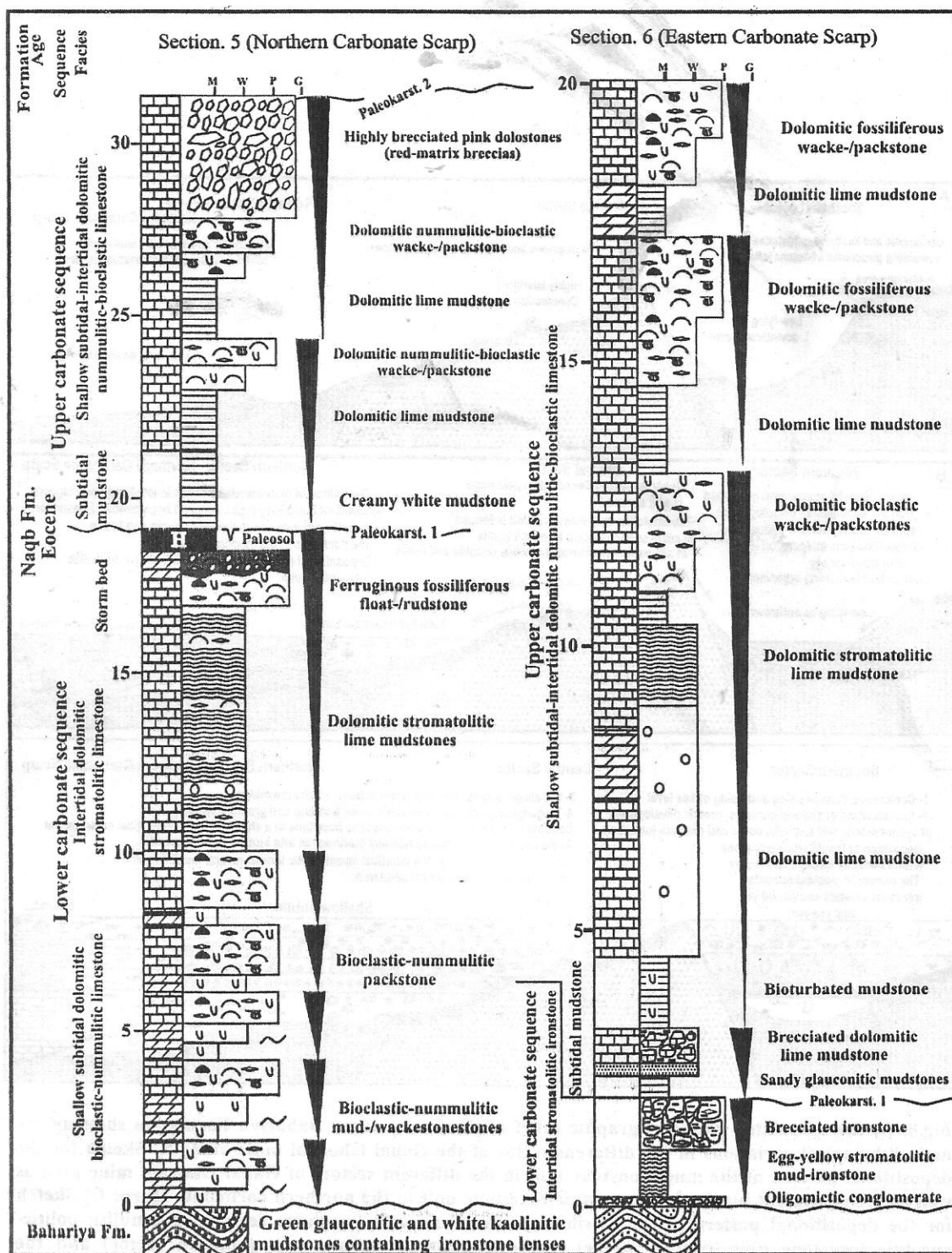


Fig.7. Facies analyses and depositional environments of the Eocene carbonate succession in the northern scarp (section 5) and the eastern scarp (section 6) surrounding Gabal Ghorabi mine area (Fig.2).

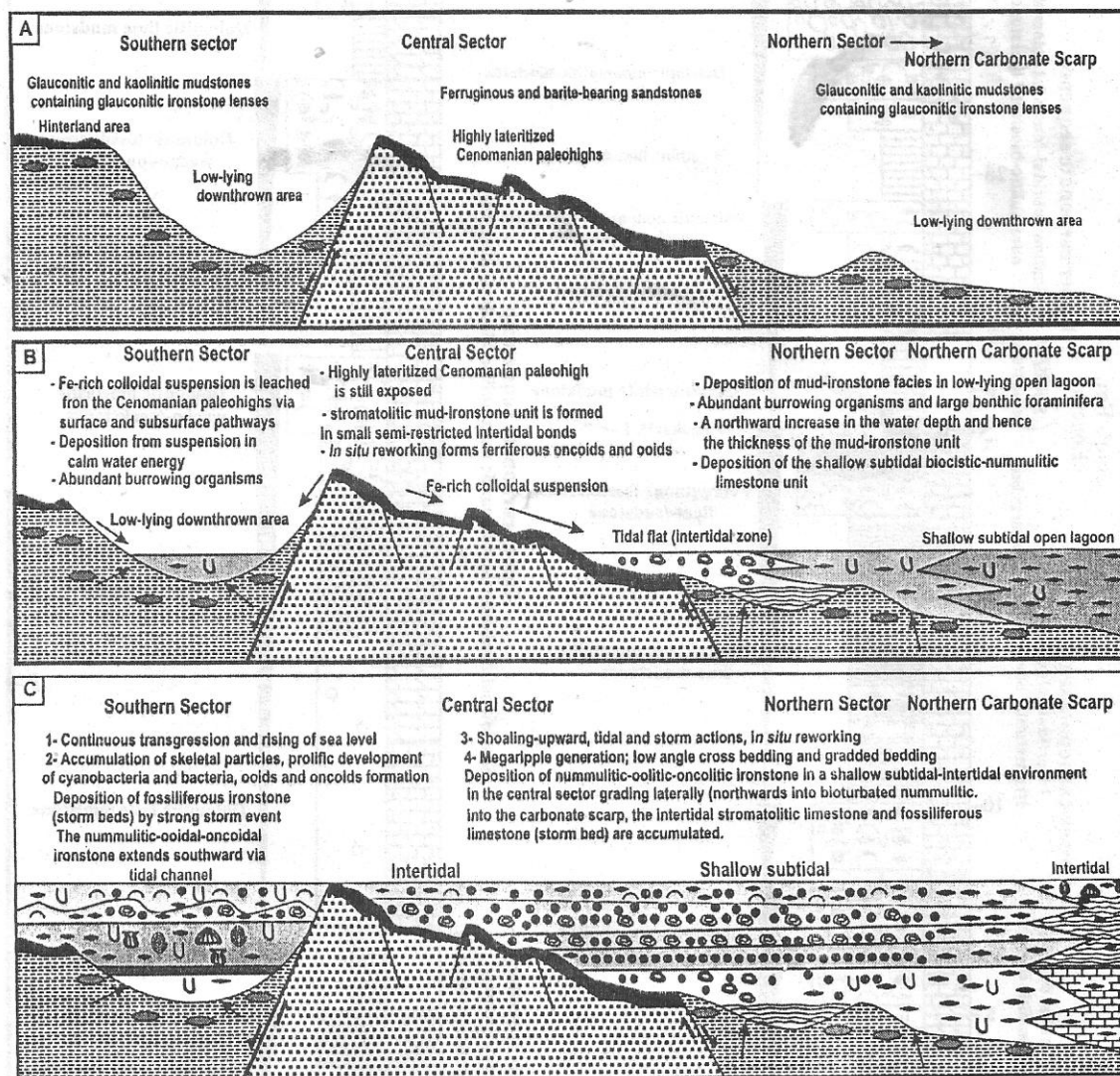


Fig.8. A) the speculated paleotopographic relief of the Cenomanian Bahariya Formation showing the main lithological variations in the different sector of the Gabal Ghorabi mine area; B) Sketch for the depositional pattern of the mud-ironstone unit in the different sectors of Gabal Ghorabi mine area as well as the equivalent bioclastic-nummulitic limestone unit in the northern carbonate scarp; C) Sketch for the depositional pattern of the fossiliferous-ironstone unit (southern sector), nummulitic-oolitic-oncolitic ironstone unit (central sector) and nummulitic ironstone unit (northern sector) and the equivalent stromatolitic limestone unit of the northern carbonate scarp.

benthic foraminifera colonize the sea bottom and increase in abundance and diversity. The wave and/or current strength, interrupted by intermittent storm currents, increase in these conditions and may *in situ* rework the nummulite tests, bioclastic debris and the underlying muddy ironstone substrate. The increase in storm intensity results in a southward extension of the nummulitic-oidal-oncoidal ironstone facies through a tidal channel. During the inter-storm calm periods, the sedimentation rate was minimum as confirmed by the presence of microbored bioclasts and burrowing organisms and thin to thick amorphous iron oxyhydroxide coatings envelop the various skeletal particles and invaded by microbes. In the mean time, in the northern carbonate scarp, intertidal stromatolitic limestone facies is developed on the open shallow subtidal bioturbated bioclastic nummulitic limestones. The intertidal stromatolitic limestone facies is covered by storm bed of fossiliferous float- to rudstones. At Naqb Ghorabi area, the stromatolitic limestone of the northern scarp is gradually changed into intertidal stromatolitic glauconitic mud-ironstones. This indicates that the Naqb Ghorabi area was a paleohigh since the deposition of the bioturbated bioclastic-nummulitic limestone facies. In the low-lying area of the southern sector, fossil lags were transported by storm current from the nearby open shallow subtidal areas and accumulated in a lagoonal environment, forming fossiliferous ironstone facies. On the other hand, in the open shallow subtidal low-lying area of the northern sector, nummulitic ironstone facies are dominated (Fig. 8 C). This facies is formed under oscillating storm wave base with intensive burrowing. On contrary, the submarine paleohigh of the central sector is dominated by shallow subtidal-intertidal nummulitic-oidal-oncoidal ironstones, arranged in five shallowing-upward cycles of variable thicknesses. The variation in thickness is attributed to the effect of pre- and syn-tectonic minor block faulting deduced from the thickness map. With a gradual-upward shoaling, the large benthic foraminifera colonize the sea bottom and increase in abundance and diversity. The wave and/or current strength, interrupted by intermittent storm currents, increase in these conditions and may *in situ* rework the nummulite tests, bioclastic debris and the underlying muddy ironstone substrate. The increase in storm intensity results in a southward extension of the nummulitic-oidal-oncoidal ironstone facies through a tidal channel. This channel has a SW trend to the western part of the southern sector and it is characterized by basal underlying fossiliferous ironstones. During the inter-storm calm periods, the sedimentation rate was minimum as confirmed by the presence of microbored bioclasts and burrowing organisms and thin to thick amorphous iron oxyhydroxide coatings envelop the various skeletal particles and invaded by microbes, forming superficial and normal ooids and oncoids.

In the mean time, in the northern carbonate scarp, intertidal stromatolitic limestone facies was developed on the open shallow subtidal bioturbated bioclastic nummulitic limestones. The intertidal stromatolitic limestone facies is covered by storm bed of fossiliferous float- to rudstones. At Naqb Ghorabi area, the stromatolitic limestone of the northern scarp is gradually changed into intertidal stromatolitic glauconitic mud-ironstones, which unconformably overlie the Cenomanian clastics of the Bahariya Formation. This indicates that the Naqb Ghorabi area was a paleohigh since the deposition of the bioturbated bioclastic-nummulitic limestone facies.

4. The ultimate result of the shoaling-upward condition is the general leveling and consuming the paleotopography with a significant fall in the Eocene sea level (sea regression). As a consequence of the sea level fall (Fig. 9A), the entire area of Gabal Ghorabi and the surrounding carbonate scarp were completely emerged and subjected to subaerial and lateritic pedogenesis inducing karstification (El Aref and Lotfy, 1989; El Aref *et al.* 1999 and Helba *et al.* 2001).
5. A sudden rising in the sea level led to the redrowning of the subaerially exposed ironstones and the surrounding equivalent carbonates. As a consequence of this new marine transgression, a shallow subtidal green mudstone facies was deposited from suspension in a calm water condition, forming a blanket of uniform thickness (Fig. 9B). This facies extends all over the study area and represents deposition under the maximum flooding surface. Early diagenetic barite nodules are observed within this facies. The upward shoaling led to the gradual vertical change from the mudstone to shallow subtidal yellowish brown bioturbated mud-ironstones and intertidal bioclastic-nummulitic ironstones (Fig. 9C). This shoaling pattern is repeated in three shallowing-upward cycles that are terminated by thin bed of stratiform barite. These barite layers are deposited in supratidal sabkha environment dominated in an isolated saline ponds of the central sector.
6. Similar to the lower ironstone sequence, the shoaling-upward tendency of the upper ironstone sequence led to a major sea level fall. This sea regression led to intensive subaerial weathering and lateritic pedogenesis and redeposition and enrichment of the iron ore.

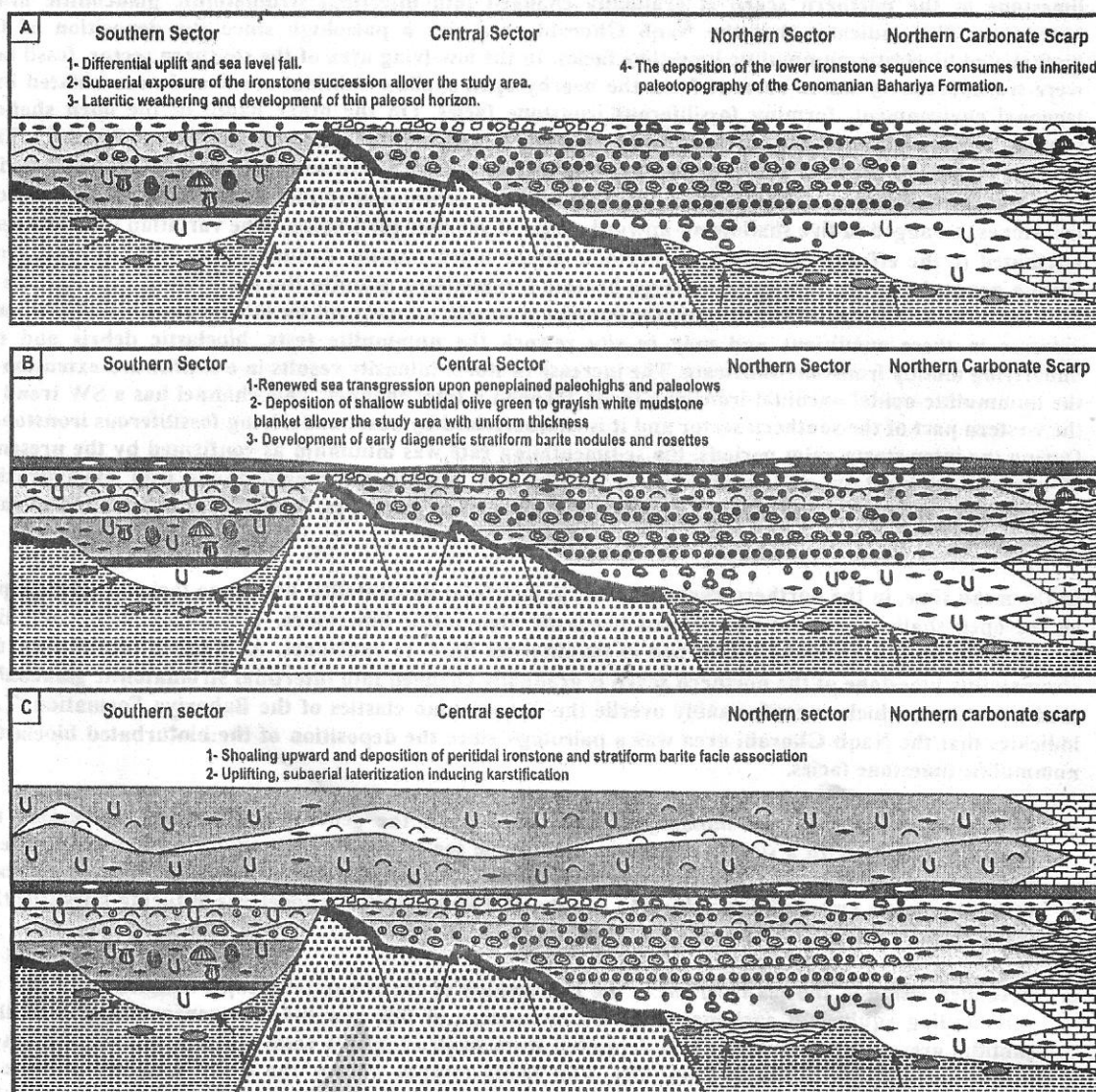


Fig. 9. A) Sketch showing the formation of the thin brick red hematitic paleosol horizon capping the lower ironstone sequence and extends all over the Gabal Ghorabi mine area and the surrounding carbonate rocks; B) Sketch showing the formation of the shallow subtidal green mudstone unit with uniform thickness all over the Gabal Ghorabi mine area and the surrounding carbonate rocks; C) Sketch showing the upward shoaling and deposition of peritidal ironstones and the stratiform barite facies associations.

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REFERENCES

- Aitken, J. D., 1967. Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southeastern Alberta. *J. Sed. Pet.*, 37, 1163-1178.
- Blondeu, A., 1972. *Les Nummulites* Paris. Librairie, Vuibert. Boulevard. Saint-Germain, 63, 254 p.
- Burkhalter, R. M., 1995. Ooidal ironstones and ferruginous microbialites: origin and relation to sequence stratigraphy (Aalenian and Bajocian, Swiss Jura mountains). *Sedimentology*, 42, 57-74.
- Chafetz, H. S. and Guidry, S. A., 1999. Bacterial shrubs, crystal shrubs, and ray-crystal shrubs: bacterial vs abiotic precipitation. *Sed. Geol.*, 126, 57-74.
- Chafetz, H. S., Akdim, B.; Julia, R. and Reid, A. 1998. Mn- and Fe- rich black travertine shrubs: Bacterially (and non bacterially) induced precipitates. *J. Sed. Pet.*, 68, 404-412.
- Cotter, E. and Link, J. E., 1993. Deposition and diagenesis of Clinton ironstones (Silurian) in the Appalachian Foreland Basin of Pennsylvania. *Geol. Soc. of American Bulletin*, 105, 911-922.
- Dahanayake, K. and Krumbein, W. E., 1986. Microbial structures in ooidal iron formations. *Min. Depos.*, 21, 85-94.
- Dahanayake, K., Gerdes, G. and Krumbein, W. E., 1985. Stromatolites, oncolites and oolites biogenetically formed *in situ*. *Naturwissenschaften*, 72, 513-518.
- Donaldson, W. S., Olint, A. G. and Longstaffe, F. J., 1999. Tectonic and eustatic control on deposition and preservation of Upper Cretaceous ooidal ironstone and associated facies. *Sedimentology*, 46, 1159-1182.
- El Akkad, S. and Issawi, B., 1963. Geology and iron ore deposits of the Bahariya oases. *Geol. Surv. Egypt, Cairo*, 18, 301 p.
- El Aref, M. M., 1984. Strata-bound and stratiform iron sulphides, sulphur and galena in the Miocene evaporates, Ranga, Red Sea, Egypt (with special emphasis on their diagenetic crystallization rhythmites). In *Syngeneses and Epigenesis In the Formation of the Mineral Deposits* (Ed. By Wauschkuhn *et. al.*), Springer Verlag, Heidelberg, 457-467.
- El Aref, M. M., 1994. Phanerozoic Stratiform and stratabound deposits of Egypt, their stratigraphic, paleogeographic, topographic and environmental control. 2nd Int. Conf. on Geology of the Arab World, Cairo Univ., Egypt, by A. Sadek (ed.), 97-124.
- El Aref, M. M. and Ahmed, S., 1986. Diagenetic crystallization rhythmites (DCRs) of dolomite-barite-calcite in karst environment, Gabal Abu Ghorban, Red Sea coastal zone, Egypt. *Proceedings of the Int. Meeting "Geochemistry of the Earth Surface and Processes of Mineral Formation"*, Granada, Spain, p. 611-622.
- El Aref, M. M. and Lotfy, Z. H., 1989. Genetic karst significance of the iron ore deposits of El Bahariya Oasis, Western Desert, Egypt. *Ann. Geol. Surv. Egypt*, XV, 1-30.
- El Aref, M. M., Abu Khadra, A. M. and Lotfy, Z. H., 1987. Karst topography and karstification processes in the Eocene limestone plateau of El Bahariya Oasis, Western Desert, Egypt. *Z. Geomorph.*, 31(1), 45-64.
- El Aref, M. M.; El Sharkawi, M. A. and Khalil, M. A., 1999. Geology and genesis of the stratabound and Stratiform Cretaceous-Eocene iron ore deposits of the Bahariya region, Western Desert, Egypt. *Gaw 4th Int. Conf. on Geol. of the Arab World, Cairo Univ., Egypt*, 450-475.
- El Aref, M. M., El Sharkawi, M. A. and Mesaed, A. A., 1996. Depositional and diagenetic microfabric evolution of the Cretaceous oolitic ironstones of Aswan, Egypt. *Egyptian Journal of Geology, Spec. Publ.*, no. 2, 280-312.
- El Aref, M. M., Helba, A. A. and Saad, F., 2001. Lutetian ramp carbonate facies; hierarchy and environments, northeast El Bahariya Depression, Western Desert, Egypt. 2nd Int. Conf. on the Geology of Africa, Assiut, Egypt, 1, 385-403.
- Fontboté, L. and Amstutz, G. C., 1980. New observations on diagenetic crystallization rhythmites in the carbonate facies of Triassic of the Alpujarrides (Betic Cordillera, South Spain). Comparison with other diagenetic rhythmites. 1st Sym. Diagenesis, Barcelona 1980, *Rev. Inst. Inv. Geol.* 34, Barcelona.
- Fuchs, Y., 1984. Migration of fluids during diagenesis: An ore-forming process in carbonate rocks. In: *Syngeneses and Epigenesis in the Formation of Mineral Deposits* (Ed. by A. Wauschkuhn, C. Kluth, and R. A. Zimmermann), p. 287-293, Berlin: Springer-Verlag.
- Gerdes, G., Dunajtschik-Piewak, K., Riege, H., Taher, A. G., Krumbein, W. E. and Reineck, H.-E., 1994. Structural diversity of biogenic carbonate particles in microbial mats. *Sedimentology*, 41, 1273-1294.

- Girgis, G. F. and Hindy, K.T., 1973. Relationship of "Nummulites gizehensis" community and lime mud bottom substratum of the Upper Lutetian sea. 4th Coll. Afr. Micropal., Abidjan 1970, Lab. Geol. Sed. Univ. Nice, p. 165-174.
- Guerrak, S., 1987. Paleozoic oolitic ironstones of the Algerian Sahara. A review. *J. Afr. Earth Sci.*, 6, 1-8.
- Helba, A. A., El Aref, M. M. and Saad, F., 2001. Lutetian oncoidal and ooidal ironstone sequence; depositional setting and origin; northeast El Bahariya Depression, Western Desert, Egypt. *Egypt. J. Geol.*, 45/1A, 325-351.
- Hermina, A., Klitzsch, E., and List, F. K., 1989. Stratigraphic lexicon na explanatory notes to the geological map of Egypt, 1: 500000, Conoco Inc., Cairo, Egypt, 207 P.
- IEP, 1993-1997. Iron ore exploration project, Cairo Univ. and EGSMA, phases I-III internal reports. Cairo Univ., Fac. Sci. Geol. Dept., report I (1993-1994, 147p.), report II (1994-1995, 161p.), report III (1995-1997, 287p.).
- Khalil, M. A., 1995. Geological and mineralogical studies on the northeastern part of El Bahariya Oasis, Western Desert, Egypt. Ph. D. Thesis, Fac. Sci. Geology Dept. El Azhar Univ., 237p.
- Kidwell, S. M. and Holland, S. M., 1991. Field description of coarse bioclastic fabrics. *Palaos*, 1, 426-434.
- Kreisa, R. D. and Bambach, R. K., 1982. The role of storm processes in generating shell beds in Paleozoic shelf environments. In: *Cyclic and Event stratification* (Ed. by G. Einsele and A. Seilacher). Berlin-Heidelberg-New York, Springer-Verlag, p. 200-207.
- Lofly, Z. H., 1988. Geological, sedimentological and mineralogical study of northeastern plateau, Bahariya Oasis, Egypt. Ph. D. Thesis, Fac. Sci. Cairo Univ., 330 p.
- Macquaker, J. H. S. and Taylor, K. G., 1996. A sequence stratigraphic interpretation of a mudstone-dominated succession: the Lower Jurassic Cleveland Ironstone Formation, U.K. *J. Geol. Soc. London*, 153, 759-770.
- Maynard, J. B., 1983. *Geochemistry of sedimentary ore deposits*. Springer-Verlag, New York, 305 p.
- Mesaed, A. A. and Surour, A. A., 2000. Mineral chemistry and mechanism of formation of the Bartonian glaucony of El Gedida mine, El Bahariya oasis, Egypt. *Egyptian Min.*, 12, 1-28.
- Moustafa, A. R., Saoudi, A., Moubasher, A., Ibrahim, I. M., Molokhia, H. and Schwartz, B., 2003. Structural setting and tectonic evolution of the Bahariya Depression, Western Desert, Egypt. *GeoArabia*, 8 (1), Gulf Petrolink, Bahrain.
- Reinson, G. E., 1992. Transgressive Barrier island and estuarine systems. In: *Facies models* (Ed. by R. G. Walker and N. P. James). *Geol. Ass. Canada*, p. 179-194.
- Sageman, B. B., Wignall, P. B. and Kauffman, E. G., 1991. Biofacies models for paleoenvironmental analysis. In: *Cycles and Events Stratigraphy* (Ed. by G. Einsele and A. Seilacher). New York, Springer-Verlag, p. 542-564.
- Said, R., 1962. *Geology of Egypt*, Elsevier publishing Co., Amsterdam, New York, 377 p.
- Said, R., 1990. Cenozoic. In: *The Geology of Egypt* (Ed. by R. Said). A. A. Balkema, Rotterdam, Brookfield, Chapter 24, p. 451-486.
- Said, R. and Issawi, B., 1964. Geology of the northern plateau, Bahariya oasis, Egypt. *Geol. Surv., Egypt*, no. 29, 41 p.
- Salama, W. S., 2005. Geology and genesis of Ghorabi iron ores and the associated barite and manganese-rich deposits, El Bahariya Depression, Western Desert, Egypt. M.Sc. Thesis, Fac. Sci, Cairo University, 245 p.
- Sehim, A. A., 1993. Cretaceous tectonics in Egypt. *Egypt. J. Geol.*, 37/1, 335-372.
- Stanton, R. L., 1972. *Ore petrology*. New York, McGraw-Hill Book Co., 731p.
- Strougo, A., Bignot, G., Boukhary, M. and Blondeau, A., 1990. The Upper Libyan (possibly Ypresian) carbonate platform in the Nile Valley, Egypt: Biostratigraphic problems and paleoenvironments. *Rev. Micropaleont.*, 33(1), 54-71.
- Strougo, A., 1996. The Lower Libyan stratigraphic succession in Farafra and Nile Valley. A new correlation. *M. E. R. C. Ain Shams Univ., Earth Sci. Ser.*, 10, 53-74.
- Tucker, M. E. and Wright, V. P., 1990. *Carbonate sedimentology*. Blackwell. Sci. Publ., Oxford, England, 482 p.
- Wilson, J. L., 1975. *Carbonate facies in geologic history*. Berlin-Heidelberg-New York, Springer-Verlag, 471 p.
- Young, T. P., 1989. Phanerozoic ironstones: an introduction and review. In: *Phanerozoic Ironstones* (Ed. by T. P. Young and W. E. G. Taylor), *Spec. Publ. Geol. Soc. London*, 46, ix-xxv.

الوضع الإستراتيجى والتحليل السحنى و البيئات الترسيبية للأحجار الحديدية التابعة لعصر الإيوسين بمنطقة جبل غرابى، منخفض الواحات البحرية، الصحراء الغربية، مصر

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الملخص

تهدف هذه الدراسة إلى توضيح الوضع الاستراتيجى والتحليل السحنى لصخور الأحجار الحديدية التابعة لعصر الإيوسين وكذلك صخور الحجر الجيري المكافئة لها بمنطقة جبل غرابى بالواحات البحرية، الصحراء الغربية، مصر. وتهتم الدراسة أيضا بتوضيح الظروف الترسيبية التى سادت أثناء تكوين هذه الصخور الحديدية وأصل وطريقة تكوين خامات الحديد بالمنطقة. أظهرت الدراسة أن رواسب الحديد المتواجدة بمنطقة جبل غرابى يحدها سطحى عدم توافق حيث ترسبت هذه الرواسب أعلى الصخور الفتاتية التابعة لعصر السينومانى (مكون البحرية) ويحدها من أعلى سطح عدم التوافق الكارستى (اللاتيريتى) الفاصل بين مكون النقب ومكون الكازون.

تمثل رواسب الحديد تتابع ترسيبى مختزل وتغير سحنى جانبى لصخور الحجر الجيرى المكافئة لها، كما تمثل الرواسب الحديدية ترسبات بحرية على إرتفاعات و منخفضات منعزلة من الصخور الفتاتية التابعة لعصر السينومانى وتأثرت أثناء تكوينها بفترات انقطاع ترسيبية و تعرية كارستية و لاتيريتية.

أظهر التحليل السحنى و الوضع الترسيبى للرواسب الحديدية أنها تتكون من عدة سحنات حديدية طينية و سحنات حديدية حبيبية تكررت فى تتابعين مختلفين يفصلهما سطح عدم توافق تأثر بعوامل تعرية كارستية و لاتيريتية أدت إلى تغير فى التركيب الأصيل للسحنات.

تم تقسيم منطقة جبل غرابى إلى ثلاث قطاعات، قطاع جنوبى و قطاع أوسط و قطاع شمالى وذلك يرجع إلى الطوبوغرافية القديمة لمكون السينومانى و التراكيب الجيولوجية المختلفة (الطيات و الصدوع الطبيعية) التى سادت فترة مابعد السينومانى و قبل و أثناء ترسيب السحنات الحديدية التابعة للعصر الإيوسينى .

يتميز التتابع السفلى للرواسب الحديدية بتغير جانبى واضح فى نوع و سمك السحنات و يبدأ برواسب حديدية طينية تكونت تحت ظروف ترسيبية هادئة فى مستنقعات طينية ضخمة فى القطاعين الجنوبى و الشمالى و سحنات حديدية طينية استروماتوليتية على مسطحات المد الشاطئية فى القطاع الأوسط. يتلو السحنات الحديدية الطينية فى القطاع الجنوبى وحدة ترسيبية من سحنات حديدية حبيبية غنية بحفريات حديدية من الرخويات و الجلد شوكيات. أما فى القطاع الأوسط فيعلو السحنات الحديدية الاستروماتوليتية وحدة ترسيبية من سحنات حديدية حبيبية مرتبة فى دورات ترسيبية ضخمة غنية بالسرديات و الأونكويزز ومختلطة مع حفريات حديدية من الفورامينيفرا القاعية الكبيرة و بعض الهياكل الطحلبية. فى القطاع الشمالى، تتركز حفريات النيوموليت و الفيولينا بشكل واضح على هيئة تموجات كبيرة. و قد تجمعت هذه السحنات فى مياه ضخمة تحت ظروف ترسيبية تتراوح من هادئة إلى عاصفة أحيانا.

ويبدأ التتابع العلوى بتقديم ملحوظ لبحر الإيوسين مع ترسيب سحنة طينية فتاتية تمتد لتشمل جميع قطاعات جبل غرابى حتى تصل إلى صخور الأحجار الجيرية المكافئة. و تكون هذه السحنة نطاق واضح متساوى السمك مما يدل على انتظام سطح المنطقة بعد انتهاء ترسيب التتابع السفلى للرواسب الحديدية. و تحتوى هذه السحنة على درنات صغيرة من الباريت تكونت بفعل عمليات ما بعد الترسيب. يتلو هذه السحنة تتابع متكرر من دورات ترسيبية ضخمة من السحنات الحديدية الطينية و الحبيبية الغنية بالفتات الأحفورى والنيوموليت مما يدل على الانتقال من ظروف ترسيبية هادئة إلى عاصفة أحيانا.

يتميز السطح العلوى لكل من التتابعين بوجود ظواهر لاتيريتية و كارستية مما يدل على التعرض لظروف تجوية هوائية و تكوين تربة حديدية قديمة.